

FRONTISPIECE.



L.K. Sherwin sculp.

London Published as the Act directs 17 May 1786 by J. Johnson in S.^t Pauls Church Yard

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AN
INTRODUCTION
TO
ASTRONOMY.

IN A
SERIES OF LETTERS,
FROM A
PRECEPTOR TO HIS PUPIL.

In which the most useful and interesting Parts of the
Science are clearly and familiarly explained.

ILLUSTRATED WITH COPPER-PLATES.

By JOHN BONNYCASTLE,
OF THE ROYAL MILITARY ACADEMY, WOOLWICH.

Docuit quæ maximus Atlas,
Hic canit errantem Lunam, Solisque labores.

VIRGIL.

L O N D O N,
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Y M O N O T A



P R E F A C E.

AT a time when the sciences are generally cultivated, and a love of literature and knowledge has pervaded every rank and order of society, an easy and familiar account of the most interesting parts of Astronomy, will, it is presumed, be found a work of considerable utility. Many, who are not sufficiently acquainted with the Mathematics, to read, with satisfaction, the works of Newton, and other eminent writers upon this subject, are yet very desirous of obtaining such an idea of it, as will enable them to comprehend the leading principles upon which it is founded, and to partake of those pleasures, which enquiries into Nature, and the investigation of some of her grandest operations, must necessarily afford to every ingenuous and inquisitive mind.

To this class of readers, the following Letters are particularly addressed. They were at first designed for the private use of an individual, without any immediate view to publication; but as nothing of the kind, sufficiently clear and explicit to answer the purpose of general information, had hitherto appeared in our language, the Author was induced to make them public, in hopes of their affording some informa-

tion to those, whose situations in life, or confined education, may have prevented them from applying to a subject, which has commonly been thought of so abstruse and difficult a nature, as to be utterly unattainable without a previous knowledge of many other branches of science.

The principal object in view, throughout the whole performance, has been to avoid, as much as possible, all complicated mathematical principles and calculations, and to elucidate the most striking particulars, in as popular and easy a manner as the nature of the subject would admit. For this purpose, such parts of the science only have been chosen, as seemed most likely to excite the curiosity and attention of the uninformed reader; and to give him a taste for those studies and pursuits, which, whilst they afford many practical advantages in some of the most important concerns of life, are of the greatest utility in forming and directing the mind, and in inculcating those liberal and enlarged ideas, which are the distinguishing characteristics of a well regulated education, and the brightest ornaments of human nature.

In a performance of this kind, which, from the nature of the undertaking, must be unavoidably deficient in many particulars, it is not to be expected that a scrupulous exactness has been always observed, or that every illustration of a subject is strictly scientific. Such a minute
attention

P R E F A C E

attention would have been incompatible with the plan of the work, and extremely difficult to have been observed, if not altogether impossible. The great object in view was to unite truth with perspicuity, and to give a general idea of the operations and phenomena of nature, independent of abstruse reasoning or laborious calculations. And though, by this means, the knowledge obtained by the Reader must, in many instances, be necessarily superficial, yet it may serve to give just ideas of the subject, and correct those notions which the prejudices of education, or the apparent view of things, might suggest.

The work being written for the purpose of general instruction, the Author has not scrupled to make a free use of the labours of preceding Writers, whenever he found any particular subject illustrated in a manner suitable to his design: and if he has not always acknowledged his obligations, it is because such alterations were commonly made as rendered it impossible, without a show of exactness which would have appeared affected and pedantic. The new matter introduced in every part of the performance, where it was most wanted; and the pains that have been taken to arrange and methodize the whole, are, it is hoped, sufficient to obviate every objection which may be made on this account, and to render all farther apologies unnecessary.

The

The frequent allusions to the Poets, and the various quotations interspersed throughout the work, were intended as an agreeable relief to minds unaccustomed to the regular deduction of facts by mathematical reasoning, and to enliven those parts, where a simple detail of particulars must, from its necessary length, become languid. Poetical descriptions, though they may not be strictly conformable to the rigid principles of the science they are meant to elucidate, generally leave a stronger impression on the mind, and are far more captivating than simple unadorned language. From a persuasion of this kind, the Author has sometimes expatiated on subjects with a warmth of expression, which may perhaps seem too florid for a philosophical performance; but which alone could delineate those elevated ideas, that must necessarily arise in the display of the sublimest scenes in nature, and the most stupendous works of creation.

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L E T.

LETTER I.

OF THE USE AND ADVANTAGE OF ASTRONOMICAL LEARNING.

DEAR SIR,

I HAVE always loved the sciences for their own sake; but I now wish to cultivate them for your's. You have convinced me, by your amiable and polite manners, that your mind is formed for the acquisition of truth and knowledge, and if I can afford you any assistance, in directing your studies and pursuits, I shall consider it as the most agreeable employment of my life.

The mode of communication you propose, is, I am afraid, less favourable to improvement, than your partiality in my favour will suffer you to imagine; but as our different situa-

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tions

tions and engagements deny me the pleasure of a personal intercourse, I shall be happy to promote your views, and contribute to your information, by every means in my power.

Astronomy seems to be the science you are desirous of being first acquainted with; and I know not that you could have made a better choice. This subject will awaken every faculty of your mind, and is, of all others, the best calculated to excite your curiosity and admiration. Not that I would wish to engage you in long calculations and laborious enquiries, which are of use chiefly to the practical proficient, who makes this the principal object of his pursuit; but there is a general knowledge of the most interesting particulars, which is so easily obtained, that it is inexcusable for a person of a liberal education to be totally destitute of it.

It is this most pleasing part of the science that I would at present recommend to your attention: and as you are but little acquainted with mathematical principles, I shall endeavour to treat of it in as easy and independent a manner as the nature of the subject will admit. To divest it entirely of its usual terms would be a vain and ridiculous attempt; but, if I do not deceive myself, I shall be able to remove every obstacle of this kind which is in the least likely to impede your progress, or prevent your improvement.

And,

And, as you are yet but a novice in the science, I shall not detain you by entering into a long dissertation on its origin and progress, but leave those particulars to be mentioned in their proper places. It will be sufficient to observe, that Astronomy is a science of the earliest antiquity, and has challenged the admiration of all ages. Poets, Philosophers, and Historians, have all given it their highest encomiums, and Kings themselves have enriched it with their labours.

The Poets, in particular, have been lavish in their praises upon this subject, and are indebted to it for some of their boldest images, and most exalted descriptions. Virgil, the greatest master of verse after Homer, speaks of it with enthusiasm; and, in his divine poem of the Georgics, breaks out into this animated apostrophe:

“ Ye sacred muses, with whose beauty fir’d,
My soul is ravish’d, and my brain inspir’d :
Whose priest I am, whose holy fillets wear ;
Would you your poet’s first petition hear ;
Give me the ways of wand’ring stars to know !
The depths of heav’n above, and earth below.
Teach me the various labours of the moon,
And whence proceed th’ eclipses of the sun.
Why flowing tides prevail upon the main,
And in what dark recess they shrink again.
What shakes the solid earth, what cause delays
The summer nights, and shortens winter days.”

DRYDEN’S VIRG.

And, in the same manner, the wisest and greatest of men, both amongst the ancients and moderns, have confessed themselves charmed with the beauties of this science. To contemplate the grand spectacle of the heavens, has ever been considered as the noblest privilege of our nature. For it is here that we discover the wonders of the Almighty, and see the wisdom of God in the works of the creation. Nor is there any knowledge, attained by the light of nature, that gives us juster ideas of this great Being, or furnishes us with stronger arguments by which to demonstrate his existence and attributes. "The heavens, says the Psalmist, declare the glory of God, and the firmament sheweth his handy work; day unto day uttereth speech, and night unto night sheweth knowledge; and there is no speech or language where their voice is not heard."

Thus Astronomy is not only valuable, as it affords us such exalted ideas of God and his works; but it also improves the mind, and increases the force and penetration of the human understanding. For, by means of this divine guide, we are taught to discover the spring and fountain of all the celestial motions; to follow the footsteps of the Creator through all the immense regions of his empire; and to trace the secret causes by which he regulates the great machine of the universe.

Were

Were a knowledge of this kind attended with no other advantage, it has rendered essential service to humanity, by dissipating our superstitious opinions and vain fears. Man is naturally timid, and terrified at dangers which he cannot foresee. Before he is familiarized with nature he suspects her constancy, and regards all her operations with dread and apprehension. The regular and invariable order of things will, at length, inspire him with confidence; but still there are some singular phenomena, that appear as alarming exceptions to the general rule.

The first total eclipse of the sun, would seem to threaten the annihilation of the universe; and the moon, in like circumstances, is going to be lost, or devoured by a dragon. The comet, with his fiery tail and blazing hair, is the harbinger of divine vengeance; his appearance announces the death of princes, the destruction of empires, famine and pestilence. This, enlightened as we are at present, was once the general language of mankind; and it is Astronomy alone that has delivered us from these evils, and taught us to look upon comets and eclipses with tranquillity and composure.

Astrology is another malady of weak minds, which is effectually eradicated by the principles of this science. We now explore the heavens for the purpose of administering to our wants

and necessities by useful discoveries, and not under the vain pretence of searching into the secret designs of fate, and the hidden events of futurity. This fallacious art, which appears so captivating to the vulgar, would have been as fatal to our peace, as it is contrary to the nature of things. Unhappy in the past, and dissatisfied with the present, we live only by the hope of what is to come. A knowledge of our future destiny, would serve only to increase the weight of our present afflictions, and by destroying every motive for exertion and activity, would render existence a misery, and the creation a desert.

But, notwithstanding the absurdity of its doctrines, this art is still practised in almost every country of the world: and it is not long since, that, even in Europe itself, the people had their cunning men, and the princes their astrologers, by whose predictions they regulated their most important concerns. It is the light of science only that can free us from the gross impositions of these wretched empiricks. The immense distance of the stars is a convincing proof that they are too remote from us, for their influence to have any effect upon our globe. Their aspects and conjunctions, which, from all eternity, have been subject to invariable laws, are totally insufficient to account for that infinite diversity of characters and passions which

we observe among men. To make every event depend upon the twinkling of a star, is an absurdity equal to that of the Lapland witches, who regulate the course of the winds by tying knots in a string.

Another singular service which astronomy has rendered to society, is the assistance it affords to the husbandman and labourer, who are employed in cultivating the earth. The whole business of agriculture depends upon a knowledge of the seasons, and the course of the sun. In every climate there are certain necessary intervals between the different operations of tillage and culture, and these intervals, being once known by experience, point out the proper time when every operation is to be performed. But how are we to know exactly, and before-hand, as is often required, the commencement of every season, and its stated continuance? This can only be done by searching in the heavens for some invariable signs, which are always connected with them, and announce their return.

These signs are indicated by the sun, or some particular star; and though the knowledge of them is but little attended to at present, it was absolutely necessary in the ancient world, when the peasant had no other guide to direct his labours than his own observations. Thus Arcturus, Orion, and the Pleiades, marked

out the several seasons of the Greeks; and the rising of Sirius with the sun, announced to the Egyptians the overflowing of the Nile, and the customary time of sowing their grain, which was immediately after its retreat. The Poets and Historians all furnish us with a number of instances of a similar kind, from which it appears, that many of the most powerful and polished nations had, for a long time, no other calendar than what was furnished by a few simple observations on the rising and setting of certain stars.

In most of the common affairs of life, nothing is more necessary than an exact measure of time. But how is this to be obtained? We have the idea of succession only from motion, and in order that the division of it into parts may be accurate, it is requisite that the motion should be constant and uniform; but such a perfect and immutable test is not to be found upon the earth. Man has in himself the principles of motion; his sensations and ideas succeed one another in a certain order; but their durations and returns are so irregular, that he can by no means employ them as a proper measure of time. The mind that suffers, and the mind that rejoices; the lover, courting his mistress, and the criminal going to execution, compute by very different reckonings.

In

It is to the heavens alone that we must look for a certain and invariable standard. Those magnificent bodies, that are placed at such immense distances from our globe, move with an order and regularity which is not to be found in any other part of the creation. From them we have obtained all our knowledge of the seasons, and the art of reckoning by certain periods of time. Had their motions been as various and mutable as those which we observe upon the earth, we should have had no idea of the regular lapse of time or the extent of duration. This is still the state of the uncivilized and solitary barbarian, who computes his time by the falls of snow, or the progress of vegetation, and is utterly ignorant of the more refined wants of society.

The interval between the rising and setting of the sun, is a measure of time which is called a day, and is what is pointed out to us by nature herself; but as we are frequently in want of a much longer period, we are obliged to have recourse to other observations than those which depend upon the appearance and disappearance of the sun. Some nations compute their time by the revolutions of the moon, or by months; some by the revolutions of the sun, or by years; and others again both by months and years. But this requires an exact knowledge of the celestial motions; and those who make use of both

both the revolutions together, should know how to conciliate, and make them agree. It was this that gave birth to the Calendar; which was for a long time extremely imperfect, has been often reformed, and is still attended with many embarrassments.

Chronology is another subject so intimately connected with astronomical observations, that without their assistance, we should have been but ill acquainted with the events recorded in history, and the transactions of past ages. But it is only since certain memorable epochas, that this art can be considered as having any solid foundation. Beyond these every thing is involved in darkness and obscurity. That uncertain tradition, which before the invention of letters, was the only vehicle of information, has confounded and disfigured every relation. We find in ancient annals but few facts that are fixed by precise dates, and even these few are seldom the same in different authors.

In this perplexed labyrinth, we have no other guide than what is afforded by the light of science. Those facts which are agreeable to the common testimony of credible historians, are considered as certain fixed points, or asylums, where the weary traveller may repose himself, after his tedious researches in the barren regions of antiquity. But the observations by which these resting-places have been determined are
very

very rare and uncommon. And what will appear still more singular, is that we owe them entirely to the gross ignorance and superstition of the times in which they were made. The phenomena of eclipses, and particularly those of the sun, were the occasion of general consternation and terror; and from the records they have left us of these alarming appearances, we are able to find the times in which they happened.

If the writings of an historian were entirely lost, and we could only obtain a certain vague relation of facts, without dates, but accompanied with an account of some remarkable eclipse; the astronomer, by his knowledge of the celestial motions, would be soon able to find the precise time in which they must have happened. It was by this means, that the celebrated Dr. Halley determined the very day and hour of Julius Cæsar's landing in Great-Britain, merely from the circumstances of his relation. And to the same cause it is owing, that the chronology of the Chinese is much more authentic than that of most other nations. From their attachment to ancient customs, and the superstition which is so intimately blended with the administration of their public affairs, they have accounts of eclipses that prove the existence of their empire for near 4000 years past.

But an advantage still more interesting and important, is the assistance which this science
affords

affords to Geography and Navigation. An acquaintance with the situation and position of different countries, is not an object of mere curiosity or useless speculation; but is now become indispensably necessary, both to the gentleman and the man of business; and is generally considered as one of the most useful branches of a polite and liberal education. Politics, commerce and philosophy, have opened a communication between almost every country on the globe. Alliances are formed between the most distant nations; traffic and science have explored every region; and the productions of different climates are transported from one extremity of the earth to the other.

When Vasco de Gama first opened the way to India by the Cape of Good Hope, and Columbus had found out a new world, the increase of riches and power resulting to certain nations from these discoveries, excited the envy and ambition of the rest, and put all Europe in motion. By a principle long established among commercial nations, the first discoverer of a new country lays claim to it as his property, and is even jealous of the way that conducted him to it. This principle, whether well or ill founded, was adopted by every power in Europe; they all became equally desirous of visiting these new climates; and the emulation for discovery con-

tinually

tinually increasing, the study of Geography, and a knowledge of the globe, became a necessary pursuit.

This science, as well as that of Navigation, was for a long time extremely imperfect and ill understood; the knowledge of distant countries was founded merely upon the vague and uncertain relation of travellers, who disfigured and exaggerated all their relations by that love of the marvellous, which is so natural and congenial to the human mind; the pilot, on the other hand, confined himself to the passing of narrow seas, or coasting along the shore, and presumed not, by any dependance upon his art, to lose sight of land, and commit himself to the mercy of the winds and waves. It was Astronomy that first inspired him with this confidence, and taught him to conduct his vessel, with safety, through immense oceans, which had never before been traversed by man.

In this difficult and hazardous enterprise, it is not sufficient for him to know the position of the port he designs to visit; he must also be able, at all times, to find upon what part of the globe he is, how far he has travelled, and what course he must pursue during the rest of his voyage. But these particulars can only be known by astronomical observations, and an accurate knowledge of the celestial motions. All the rules of the art are derived from this source,

source; and though their application be attended with some difficulties, it is of the utmost importance to every mariner that they should be well understood, and properly practised; since the lives of his men, and the success of his voyage, depend upon the knowledge of them.

The government, in most countries, are so sensible of the truth of these observations, that, of late years, they have paid the utmost attention to pilotage and navigation. Since the maritime has become the preponderating force, Astronomy has been considered as a science of great public utility, intimately connected with the interest of the state, and deserving the protection of every commercial nation. The great encouragement given to the professors of this science by Louis the XIVth and XVth of France; the noble reward offered by the English for the discovery of the longitude at sea; and the expensive voyages that have been undertaken for observing the transit of Venus over the sun, are all sufficient proofs of its extensive application, and practical importance.

Such are the advantages which society have derived from the cultivation of this excellent science; but there is yet another, which though less evident to the world in general, is nevertheless inestimable in the eyes of a philosopher. This is the knowledge of nature; the true system of the world; and the invariable laws by which

which it is governed. Astronomy has opened to us such a magnificent view of the creation, that we are struck with astonishment at the grandeur of the spectacle, and the powers of Omnipotence. By looking abroad into the universe, we exalt our ideas of the supreme intelligence, and extend the narrow sphere of human conceptions; the faculties are strengthened and improved; the understanding is enlarged; and the mind, in the contemplation of so many glorious objects, finds itself drawn to that great Being who informs, directs, and animates the whole.

This formal defence of a science attended with so many obvious advantages, would have been totally unnecessary, had I consulted only my own prepossessions in its favour; but as you are yet but little acquainted with the subject, and cannot possibly have obtained any rational conviction of its excellence, I imagined it would not be unpleasing to you, to receive some account of its practical utility and importance. To enumerate every particular of this kind, would be useless and impossible. An attentive consideration of the subject, will be more satisfactory than any previous information that can possibly be given you.

In order to form a proper judgment of any science, it is necessary to have some knowledge of its nature and design. For want of this assistance,

ance, many writers, and even some of considerable eminence in other respects, have been egregiously mistaken when they have presumed to give their opinions upon subjects which were unconnected with their own particular studies and pursuits. Some err through ignorance, and some through prejudice. Narrow minds judge of excellence only by the standard of their own acquisitions; and whatever deviates from this is folly and absurdity.

Actuated by a principle of this kind, the present idol of modern literature, the author of the Rambler, has been led to speak of the mathematical sciences in a manner unworthy of his abilities. "It was, says he, the great praise of Socrates, that he drew the wits of Greece, by his instruction and example, from the vain pursuit of natural philosophy to moral enquiries; and turned their thoughts from stars, and tides, and matter, and motion, to the various modifications of virtue, and relations of life."

This thought is pursued still further, and illustrated by a ridiculous story which he tells of one Gelidus, a mathematician, who was so absorbed in his speculations, that when his servant came to acquaint him a house was on fire, and the whole neighbourhood in danger of being burnt, he only replied, that it was very likely, for it was the nature of fire to act in a circle

circle. He even divests poor Gelidus of all the common feelings of humanity, and makes him as insensible to the wants of his family, as to the distresses of his neighbours.

This fiction is as applicable to the speculator upon morals, as to the speculator upon mathematics. There are Quixotes and pedants in every profession. Instead of attempting to ridicule a science of which he was totally ignorant he would have done well to have learnt it himself. The mere theorist, whatever be his pursuit, is a useless member of society; but we should be careful, when we laugh at the absurdities of a visionary pretender, not to depreciate the science to which he has unhappily directed his attention. Swift ridicules mathematicians, and mathematicians enjoy the satire; not because it is founded in truth, but because it has wit and humour.

The learned Joseph Scaliger proceeded in a still more singular manner; he was a man that aimed at universal knowledge; and being particularly desirous of eminence in the sciences, he published a large volume of mathematics, in which he professed to have solved all the difficult problems, which had been considered as the master-pieces both of ancient and modern proficients: but when this wonderful work came to be examined, it was found that he was utterly unacquainted with the subjects he had attempted

tempted to discuss. Clavius exposed his ignorance; and he, in return, not only abused Clavius, and the rest of the mathematicians, but even reviled the science itself.

A great and comprehensive genius excludes none of the sciences; they are all of them the ornaments and embellishments of life: and, for that reason, ought to be cultivated and improved. Happy is the mind that is not contracted by the study of philosophy, nor enervated by the charms of the Belles Lettres; that can be strengthened by Locke, instructed by Clarke and Newton; impassioned by Cicero and Demosthenes; and elevated by the powers of Homer and Virgil.

I am, &c.

LET-

LETTER II.

OF THE FIGURE AND MOTION OF THE EARTH.

IN my last letter I have shewn you the excellence and advantage of Astronomical Learning in general. I shall now come to particulars; and endeavour to lead you, by gentle and easy steps, from the first principles of the science, to those parts which are the most interesting and useful. And as the earth we inhabit is constantly subject to our observation, and is that with which we are the most acquainted, a description of its form and magnitude will naturally excite your curiosity and attention.

This vast body was long considered as a large circular plane, spreading out on all sides to an infinite distance: And the heavens, above it, in which the sun, moon and stars appeared to move daily from east to west, were imagined to be at no great distance from it, and to have been created solely for the use and ornament of our earth. Of this notion are the vulgar, and those who are ignorant of Astronomy, to this day. But the opinion, which is defended at present by all mathematicians and philosophers,

is, that the earth is of a round or spherical figure, nearly resembling that of a globe.

The truth of this opinion, is evident from the voyages of those famous navigators Magellan, Sir Francis Drake, Lord Anson, Cooke, &c. who all set out, at different times, to sail round the world; and, by steering their course continually westward, arrived, at last, at the place from whence they departed; which could never have happened, had the earth been of any other than a spherical or globular figure.

This form is also sufficiently apparent, from the circular appearance of the sea itself, and the circumstances which attend large objects when seen at a distance on its surface. For, when a ship goes out to sea, we first lose sight of the hull, or body of the vessel; afterwards of the rigging; and at last discern only the top of the mast; which is certainly owing to the convexity of the water between the eye and the object; or otherwise, the largest and most conspicuous part would have been visible the longest, as is manifest from experience.

Another proof, which is of no less force than either of the former, is taken from the shadow of the earth, upon the face of the moon, in the time of a lunar eclipse. For as the moon has no light but what it receives from the sun, and as the earth, at this time, is interposed between them, the moon must, in part, become
obscure.

obscure. And since this obscure part is always bounded by a circular line, the earth itself, for that reason, must certainly be spherical. Because it is evident, that none but a spherical body can, in all situations, cast a circular shadow.

Nor are the little unevennesses on the earth's surface, arising from hills and vallies, any material objection to its being considered as a round body; since the highest mountains we are acquainted with, bear a less proportion to the whole bulk of the earth than the small risings on the coat of an orange bear to that fruit; or a grain of sand, to an artificial globe of nine inches diameter. And accordingly we find, that these trifling protuberances occasion no irregularities in the shadow of the earth, during the time of a lunar eclipse; but that the circumference thereof always appears to be even and regular, as if cast by a body truly globular.

A number of other proofs might be given to the same purpose; but these are the most popular, and are such as I apprehend must entirely convince every impartial enquirer, whose object is truth, and whose mind is unclouded by superstition, or an obstinate attachment to early notions and vulgar prejudices.

I mention this the more particularly, because, notwithstanding the clearest arguments

and most decisive demonstrations, there have been some who have violently opposed this doctrine, and even represented it as dangerous to religion and morals. Thus, several of the ancient fathers went so far out of their province, as to pronounce it heretical for any person to declare there was such a thing as the Antipodes, or people who lived opposite to us upon the globe.

They took their objection from some passages of scripture, which they either ill understood, or strangely perverted from their true meaning. For it is evident, that the sacred writers speak every where according to the common appearance of things ; and were not so solicitous of instructing us in Philosophy and Astronomy, as of making us good men, and laying before us a plain rule of faith and conduct.

It is not known who was the first that asserted the figure of the earth to be spherical ; but the doctrine is certainly very ancient. For at the taking of Babylon by Alexander the Great, eclipses were found to have been set down and computed for many centuries before the birth of Christ ; which, without a knowledge of the globular figure of the earth, could not have been done.

Thales the Milesian, who lived about 600 years before Christ, must likewise have been sufficiently acquainted with this subject ; since, accord-

according to the testimony of Herodotus, he predicted an eclipse of the sun. "After the war, says he, had been carried on for six years between the Medes and Lydians, as they were going out to battle, the day became presently as dark as the night; which change had been predicted by Thales to the Ionians."

It appears therefore that, in those early times, the true figure of the earth was not unknown in the world. But it is also equally certain, that this knowledge was confined to a very few; and that even some of the greatest poets and mathematicians themselves were ignorant of it. Thus Heraclitus, that ancient philosopher, supposed it to have the shape of a skiff or canoe. Anaximander imagined it to be cylindrical; and Leucippus in the form of a drum.

These, and many more absurd opinions of the same kind, which Aristotle and others attribute to the ancients, plainly shew the confusion and uncertainty which, at that time, attended the subject. But it is the glory of modern philosophers, that this doctrine is now set in so clear a light, and the knowledge of it so generally diffused, that it is almost impossible it should ever again be forgotten; or that the ravages of ignorant barbarians, should involve it in doubt and obscurity.

We are now certain, that the earth is not a level horizontal plane, stretched out infinitely on all sides, and with a bottomless foundation. But that it is a globular body, suspended in the void space, and covered on all sides with innumerable inhabitants; who, by means of the arts of navigation and commerce, can carry on a correspondence with each other, and transport their commodities to the most distant regions.

Having said thus much concerning the figure of the earth, I might now proceed to give you some account of its bulk and magnitude; for this also has been actually ascertained; and is now settled, by Mathematicians, to a sufficient degree of accuracy and precision. But as the method by which the measurement of this large body was effected, as well as several other matters relating to the true figure of the earth itself, depend upon principles which will be better explained hereafter, I must defer entering into those particulars till you are further advanced in the science, and properly prepared to understand them.

That the true magnitude can be determined is not to be doubted. For the form of the earth being once known, its bulk could not long remain a secret. Accordingly we find that several of the ancient philosophers, who lived soon after the time of those before mentioned, attempted the solution this curious problem.

And

And though the measures they have given are considerably wide of the truth, as well as different from each other, yet this was owing more to the inaccuracy of their instruments, and the want of a sufficient stock of mathematical knowledge, than to any real difficulty or impracticability in the thing itself.

But let us leave this subject for the present, and proceed to another of equal importance. I have before proved to you, from the most indubitable arguments, that the earth is a globular body, unsupported by pillars of a bottomless foundation, as many have absurdly imagined; I shall now give you some account of its motion; a thing more remote from vulgar apprehension than the former, though equally certain and demonstrable.

And, in order that you may obtain as clear and comprehensive an idea of this subject as possible, we will first take a view of the universe in general, and of that part of it, in particular, which Astronomers have called the visible world, or solar system.

By the universe then, we are to understand the whole frame of nature, even to the utmost extent of the creation. And, by the solar system, is meant that portion of the universe only, which comprehends the sun, planets, satellites, and comets. Of this system the sun is supposed to be the center; and it is now fully
proved

proved by Astronomers, that there are six planets moving round him, each in its own path or orbit. The names of these planets, according to their distance from the center or middle point of the sun, are, Mercury, Venus, the Earth, Mars, Jupiter, and Saturn. The two first, because they move within the earth's orbit, are called inferior planets; and the three last superior, from their moving without the earth's orbit.

Now if we can form a notion of the manner in which our earth moves, we shall easily conceive the motions of all the rest of the planets, and by that means obtain a complete idea of the order and œconomy of the whole system. And, in order to this, nothing more is necessary than to consider the common appearances of the heavens, which are constantly presented to our view, and attend to the consequences. For since it is well known that the sun and stars appear to move daily from east to west, and to return nearly to the same places in the heavens again in twenty-four hours, it follows that they must really move, as they appear to do, or else that we ourselves must be moved, and attribute our motion to them: it being a self-evident principle, that, if two things change their situation with respect to each other, one of them, at least, must be moved,

But



But if this change be owing to the revolution of the stars, we must suppose them to be endowed with a motion so amazingly swift as to exceed all conception. Since it is now known, by calculations founded on the surest observations, that their distance from us is so immense, and the orbit they have to run round so prodigiously great, that they would move at least 100,000 miles in a minute. Now as nature never does that in a complicated and laborious manner which may be done in a more simple and easy one; it is certainly more agreeable to reason, as well as to the power and wisdom of the Creator, that these effects should be produced by the motion of the earth; especially as such a motion will best account for all the celestial appearances, and, at the same time, preserve that beautiful simplicity and harmony, which is found to prevail in every other part of the creation.

And this argument will appear still stronger, if we compare the vast bulk of the celestial bodies with the bulk of our earth. For it is well known to Astronomers, that the sun is near a million of times bigger than the earth; and some of the stars are found to be still larger. It is much more probable therefore, that the earth revolves round its axis, with an easy natural motion, once in twenty-four hours, than that those vast bodies should be carried from one

one place to another, with such incredible swiftness.

Nor is it any objection to this rotation of the earth, that we are unable to perceive it. For as the motion of a ship at sea, when she sails swiftly over the smooth surface of the water, is almost imperceptible to the passengers and company on board; much more so must it be with such a large body as the earth, that has no impediments or obstacles of any kind to meet with in its way, or to disturb its motion; which, for that reason, must be constantly regular and uniform.

And, in a manner equally easy, may another objection be removed, which has frequently been brought against this doctrine. It has been asserted, that if the earth moved, a stone dropped from the top of a tower, or any other high building, would not fall just at the bottom of it, as the building must have advanced considerably forward during the time of the fall. But this is evidently a mistake; for it is well known, by repeated experiments, that if a body be projected from another body in motion, it will always partake of the motion of that other body. Thus a stone dropped from the top of a mast, whilst the ship is under sail, is not left by the vessel, but falls exactly at the foot of the mast. And if a bottle of water be hung up in the cabin with its neck downwards, it will
empty

empty itself, drop by drop, into another bottle placed exactly underneath it, though the ship shall have run many feet whilst each drop was in the air.

This motion of the earth round its axis, which I have thus sufficiently proved, is called its diurnal, or daily motion, and is that which occasions the regular return of day and night, and all the celestial appearances before mentioned. But there is also another motion of the earth, round the sun, called its annual, or yearly motion, which occasions the grateful vicissitudes of the seasons, summer, winter, spring, and autumn.

Now, this second motion of the earth, or its annual revolution round the sun, may be easily gathered from celestial appearances, in nearly the same manner as the diurnal revolution. For as that luminary seems to move round the earth, from east to west, in the space of a day, which is really owing to the diurnal revolution of the earth upon its axis, in a contrary direction, so, likewise, he seems to have an annual motion in the heavens, and to rise and set continually in different parts of them; which is certainly occasioned by the daily motion of the earth in its orbit, or path round the sun, which it completes in the space of a year.

That the earth is not the center of the celestial motions, may also be easily shewn from the revolutions

volutions and appearances of the different planets which belong to our system. For it is certain, that wherever the sun be placed, the orbit of Venus actually surrounds and incloses him within itself; and therefore Venus, whilst she describes this orbit, must really move round the sun. For this planet is observed to be sometimes above, or beyond the sun; and sometimes below him, or between the sun and us. But she was never known to come in opposition to the sun, or to be seen in the east when he was in the west; which would necessarily have happened, if she had performed her revolution round the earth either in a longer or shorter time than the sun.

After the same manner, Mercury is always found to keep himself in the neighbourhood of the sun, without ever receding from him so far as Venus; but as he is continually hid in the splendor of the sun's rays, he can seldom be seen without the assistance of a telescope. The exceeding brightness by which this planet outshines all the others, is likewise a sufficient proof, that he must be much nearer to the sun than any of the rest; and from all this it is evident, that the orbit of Mercury is included within the orbit of Venus, and that he also regards the sun as the center of his motion.

Mars, Jupiter, and Saturn, being superior planets, must necessarily include the earth in their
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their

their orbits; but from their different elongations, or distances from the sun, as well as from their stationary and retrograde appearances, it is plain that the sun, and not the earth, must also be the center of their motions, or the body round which they perform their different periods and revolutions.

And from hence it follows, that the earth itself must likewise move round the sun. For since, by the place it obtains in the system, it has those moveable bodies Mercury and Venus on one side, nearer to the sun, and Mars, Jupiter, and Saturn, on the other side, more remote, it being of the same nature as they are, must needs partake of the same sort of motions. And as the earth is in the middle, between Venus and Mars, so the period likewise in which it performs its course round the sun, is a mean between the periods of those planets, being greater than the one, and less than the other, as would naturally follow from such a motion.

The absurdity of supposing the earth a sedentary and immoveable body, is admirably described in the following speech of Adam to the angel Raphael, when he is enquiring concerning the nature of the celestial motions:

“ When I behold this goodly frame, this world
Of heav’n and earth consisting, and compute

Their

Their magnitudes, this earth a spot, a grain,
 An atom, with the firmament compar'd
 And all her number'd stars, that seem to rowl
 Spaces incomprehensible (for such
 Their distance argues, and their swift return
 Diurnal) merely to officiate light
 Round this opacous earth, this punctual spot,
 One day and night; in all their vast survey
 Useless besides, reasoning I oft admire
 How Nature, wise and frugal, could commit
 Such disproportions."——

MILTON'S PARADISE LOST.

Many other proofs might be given, which
 establish this doctrine upon the surest founda-
 tion, and secure the abettors of it from all
 possibility of contradiction. But in a thing
 which admits of absolute certainty, there have
 been those who were so perversely ignorant as
 to refuse all conviction. This opinion of the
 motion of the earth, like that of its figure, has
 met with continual opposition; and its advo-
 cates have been branded with the most igno-
 minious titles, and persecuted with all the rage
 of fanaticism.

Thus, the celebrated Aristarchus of Samos, for
 defending this opinion, was brought before the
 bench of the Areopagites, and accused, by his
 adversary, of having violated the laws of reli-
 gion and morality. And, not 200 years since,
 the great Galileo met with the same fate. He
 was

was summoned before the tribunal of the Inquisition, and obliged solemnly to abjure his astronomical tenets; that the sun was immovable, in the midst of the universe, and that the earth moved round it as its proper center. This he was compelled to do, and to declare that he did with a sincere heart, and faith unfeigned, abjure, curse, and detest, the aforesaid errors and heresies.

Such are the obstructions that have been constantly thrown in the way of science and knowledge. But, happily for mankind, the persecuting spirit of bigotry and enthusiasm is now losing ground; and the dogmas of papal authority, are as little regarded as the infallibility of its decisions. Philosophers, of every country, embrace the doctrine of Galileo, whilst his accusers can boast of no converts but the ignorant and credulous.

LETTER III.

OF THE SOLAR SYSTEM, AND THE FIRMAMENT OF
THE FIXED STARS.

AS the figure and motion of the earth are now sufficiently established, it will be proper to turn our attention to the rest of the planets; and, from describing their nature and properties, to exhibit a summary view of the whole system.

In the first place, then, it is to be observed, that the planets are all opaque spherical bodies, like our earth, that have no proper light of their own, but shine by means of the borrowed light which they receive from the sun: for it is well known, from telescopical observations, that only that side of them which is turned towards the sun is ever illuminated; whilst the opposite side, which the borrowed rays cannot reach, remains continually dark and obscure.

And the planets are not only similar to our earth in form and structure, but they likewise perform their circulations exactly in the same manner. From the regular appearance and disappearance of several remarkable dark spots, which,

which, by means of a telescope, are constantly to be seen on their bodies, we are able to demonstrate that they must have such a rotatory motion round their axis, as answers to the diurnal revolution of the earth. And from their seeming at some times to be stationary, and at other times to go backwards, or to be retrograde, we are also equally certain, that they must have such a progressive motion round the sun, as answers to the annual revolution of the earth in its orbit.

Mercury, the nearest planet to the sun, goes round him in about eighty-seven days and twenty-three hours, or a little less than three months; which is the length of his year. But being seldom seen, on account of his nearness to the sun, and no spots appearing on his surface or disk, the time of his rotation upon his axis, or the length of his days and nights, is as yet unknown. His distance from the sun is computed to be about thirty-seven millions of miles, and his diameter 3200 miles; and in his course round the sun, he moves at the rate of 105,000 miles every hour.

This planet, when viewed at different times with a good telescope, seems to have all the various phases or appearances of the moon, except that he is never seen quite full; because his enlightened side is never turned directly towards us, but when he is so near the sun as to be hid in his beams. And from this it is

plain, that he does not shine by any light of his own, for if he did, he would certainly appear round like the sun.

Venus, the next planet above Mercury, is computed to be sixty-eight millions of miles from the sun; and, by moving at the rate of seventy-six thousand miles every hour, she completes her revolution round the sun in 224 days and seventeen hours, or about seven months and a half. Her diameter is 7700 miles, and her diurnal rotation on her axis, is performed in twenty-three days and twenty-two hours.

When this planet appears to the west of the sun, she rises before him in the morning, and is called the Morning Star; and when she appears to the east of the sun, she shines in the evening, after he sets, and is then called the Evening Star; being in each situation, alternately, for about 290 days: and during the whole of her revolution, she appears through a telescope to put on all the various shapes and appearances of the moon.

The next planet above Venus, in our system, is the Earth. Its distance from the sun is ninety-five millions of miles, and by travelling at the rate of fifty-eight thousand miles every hour, its annual revolution is performed in 365 days, five hours, and forty-nine minutes, or the space of a year; which motion, though

120 times swifter than that of a cannon-ball, is but little more than half the velocity of Mercury in his orbit. The earth's diameter is 7900 miles; and by turning round its axis every twenty-four hours, from west to east, it occasions the apparent motions of all the heavenly bodies from east to west in the same time.

The planet next above the Earth's orbit, is Mars. His distance from the Sun is computed to be about 144 millions of miles; and by travelling at the rate of fifty-five thousand miles an hour, he goes round the Sun in a little less than two of our years. His diameter is 4200 miles; and his diurnal rotation upon his axis is performed in about twenty-four hours and thirty-nine minutes. This planet sometimes appears gibbous, but never horned; which plainly shews, that his orbit includes that of the earth, and that he shines not by his own native light.

Jupiter, the largest of all the planets, is still higher in the system than Mars. He is reckoned to be about 490 millions of miles from the Sun, and by going at the rate of twenty-nine thousand miles an hour, completes his journey in something less than twelve of our years. His diameter is computed to be 89,000 miles, and by a prodigiously rapid motion upon his axis, he performs his diurnal rotation in nine hours and fifty-six minutes.

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Saturn,

Saturn, the next planet in the system above Jupiter, is about 900 millions of miles from the Sun; and by travelling at the rate of twenty-two thousand miles an hour, he performs his annual circuit round the Sun in about twenty-nine and a half of our years. His diameter is 79,000 miles; but on account of his immense distance, and the deficiency of light occasioned by such a remote situation, the time of his diurnal rotation upon his axis has not yet been discovered.

This has commonly been thought the most remote planet in our system; but another, at a still greater distance, has lately been discovered by Mr. Herschel, the particulars of which, as they are new and interesting, I shall speak of more at large in some future letter. At present it is only necessary to observe, that besides the primary planets here mentioned, there are ten others, called secondary planets, or satellites, which regard their primaries as the centers of their motions, and revolve round them in the same manner as those primaries revolve round the Sun.

One of the most conspicuous of these satellites is the Moon, who is a constant attendant on our Earth; and, whilst she accompanies it in its annual progress through the heavens, keeps revolving round it continually, by a different motion, in the space of a month. The Moon's
diameter

diameter is 2,180 miles, her distance from the Earth 240,000; and in bulk she is about sixty times less than the Earth. Jupiter has four such Moons, and Saturn five; and from the continual change of their phases, or appearances, it is evident that these also are opaque bodies, like the rest of the planets, and shine only by means of the borrowed light which they receive from the Sun.

The periods, distances, &c. of these moons, together with many other tables of the same kind, are usually given by astronomical writers; but as a minute detail of particulars can only be of service to those who have made farther advances in the science, I have omitted them.

A number of other circumstances, relating to this subject, will be mentioned in their proper places. But a general idea of the solar system, and whatever relates to the periods, distances, bulks, &c. of the planets, will be best acquired from the following table, which is formed from the latest observations of the best modern Astronomers, who have written upon this subject. A minute exactness in these matters, cannot be easily obtained; and as the nearest round numbers are better retained in the memory than those which are more accurate, I have preferred this method of expressing them for the present, but when occasion requires shall be more precise.

Anno 1784.	MERCURY.	VENUS.	EARTH.
Greatest possible elongation of inferior, and parallax of superior planets, - -	28°. 20'	47°. 48'	* * *
Proportional mean distances from the sun,	.38710	.72333	1.00000
Periodical revolutions,	87 d. 23 h. 15½ m.	224 d. 16 h. 49½ m.	365 d. 6 h. 9½ m.
Diurnal rotations, -	* * *	23 h. 22 m.	23 h. 56 m. 04 f.
Inclinations of their orbits to the ecliptic, - - - -	7°. 00'	3°. 23½'	* * *
Eccentricities, - -	7960	510	1680
Place of the ascending node, - - - -	1 f. 15 d. 46½ m.	2 f. 14 d. 44 m.	* * *
Place of the aphelium,	8 f. 14 d. 13 m.	10 f. 9 d. 38 m.	9 f. 9 d. 15½ m.
Greatest apparent diameters, - - -	11"	58"	*
Diameters in English miles; that of the sun being 883,217	3.222	7.687	7.964
Mean distances from the sun in semidiameters of the earth,	9210	17210	23799
Mean distances from the sun in English miles,	37.000.000	68.000.000	95.000.000
Proportions of light,	6.68	1.91	1.00
Proportion of bulk; that of the sun being 1.380.000 -	$\frac{1}{13}$	$\frac{8}{9}$	1
Proportion of density; that of the sun being $\frac{1}{4}$ - - - -	2	$1\frac{1}{4}$	1

MARS.	JUPITER.	SATURN.	GEORGIUM SIDUS, 1782.
47°. 24'	110. 51'	6°. 29'	3°. 41'
1.52369	5.20098	9.53937	19.03421
686 d. 23 h. 30½ m.	4332 d. 8 h. 51½ m.	10761 d. 14 h. 36½ m.	30445 d. 18 h.
24 h. 39 m. 22 f.	9 h. 56 m.	* * *	* *
1°. 51'	1°. 19½'	2°. 30½'	46'. 12"
14218	25277	53163	4759
1 f. 17 d. 59 m.	3 f. 8 d. 50 m.	3 f. 21 d. 48½ m.	3 f. 13 d. 1 m.
5 f. 2 d. 6½ m.	6 f. 10 d. 57½ m.	9 f. 0 d. 45½ m.	11 f. 23 d. 23 m.
25"	46"	20"	4"
4.189	89.170	79.042	35.109
36162	123778	227028	453000
144.000.000	490.000.000	900.000.000	1.800.000.000
.43	.037	.011	.00276
$\frac{7}{14}$	1.400	1000	90
$\frac{7}{10}$	$\frac{23}{100}$	$\frac{2}{100}$	* *

The two planets, Jupiter and Saturn, besides the number of their Moons, are distinguished from the rest in a still more remarkable manner. The body of Jupiter is surrounded by several parallel faint substances called Belts. And Saturn has a magnificent luminous Ring, which encompasses him, at such a distance, that several of the stars may be frequently seen between the inward surface of the ring and the body of the planet. But neither these appearances, nor the satellites themselves, can be discerned without the assistance of a telescope.

The Comets are now the only bodies belonging to our system, which remain to be mentioned; and of these the number is unknown. But from the observations which have been made on them, it has been found that they move round the Sun, and cross the orbits of the planets in all manner of directions. They are also solid opaque bodies, of different magnitudes, like the planets; and are distinguished from them principally, by long beards of transparent hair, or fiery tails, which continually issue from that side of them which is furthest from the Sun.

The orbits in which these vast bodies move are exceedingly long ovals, or very eccentric ellipses, of such amazing circumferences, that in some parts of their journey through the heavens, they approach so near the sun, as to be almost

almost vitrified by his heat; and then go off into the regions of infinite space, to such immense distances, as to be totally deprived of the light and heat, which the rest of the planets receive from that luminary.

What a magnificent idea of the Creator and his works is here presented to the imagination! The sun, a stupendous body of fire, is placed in the center of the system, round whose orb, the planets, satellites, and comets, perform their revolutions, with an order and regularity that must fill our minds with the most exalted conceptions of their divine Creator. Who can contemplate the magnitudes and distances of these vast bodies, and the beautiful harmony of their motions, and not be struck with the grandeur of the scene, and the wonderful power of omnipotence! But what must be our astonishment when we are told, that this glorious system, with all its superb furniture, is only a small part of the universe; and if it could be wholly annihilated, would be no more missed, by an eye that could take in the whole creation, than a grain of sand from the sea-shore.

To form a proper idea of the extent of the universe, and the more glorious works of creation, we must turn our attention to the starry firmament; and visit those numerous and splendid orbs which are every where dispersed through

through the heavens, far beyond the limits of our planetary system.

“ We, though from heav’n remote, to heav’n will move
 With strength of mind, and tread the abyss above ;
 And penetrate, with an interior light,
 Those upper depths, which nature hid from sight.
 Pleas’d we will be to walk along the sphere
 Of shining stars, and travel with the year,
 To leave the heavy earth, and scale the height
 Of Atlas, who supports the heav’nly weight.
 To look from upper light, and thence survey
 Mistaken mortals wand’ring from the way.”

OVID’S METAMORPHOSIS.

It is in these higher regions, that the Almighty has displayed himself in such indelible characters as must rouse the most insensible spectator, and fill his mind with admiration and astonishment. By contemplating the magnitudes and distances of the fixed stars, all partial considerations of high and low, great and small, vanish from the mind ; and we are presented with such an unbounded view of nature, and the immensity of the works of creation, as overpowers all our faculties, and makes us ready to exclaim with the Psalmist, “ Lord, what is man, that thou art mindful of him, or the son of man, that thou regardest him ? ”

The fixed stars are distinguished from the planets by being more bright and luminous, and by continually exhibiting that appearance

which we call the scintillation, or twinkling of the stars. This, probably, arises from their appearing so extremely small, that the interposition of any very minute substance, of which there are many constantly floating in the atmosphere, deprives us of the sight of them: but the interposed body soon changing its place, we again see the star; and this succession being perpetual, occasions the twinkling.

But a more remarkable property of the fixed stars, and that from which they obtained their name, is their never changing their situation with regard to each other, as the planets do. For though the revolution of the earth upon its axis occasions an apparent daily motion of the whole frame of the heavens, in a contrary direction; yet any two fixed stars being observed, at several distant intervals of time, will be found to preserve the same relative position during the whole of this revolution.

It is not to be imagined, that the stars are placed in one concave surface, so as to be all equally distant from us; but that they are dispersed through unlimited space, in such a manner, that there may be as great a distance between any two neighbouring stars, as there is between our sun and those which are the nearest to him. So that an observer, who was placed near any fixed star, would consider it alone as a real sun, and the rest only as so many

many shining points, placed at equal distances from him in the firmament.

Those stars which are the nearest to us seem the largest, and are therefore called stars of the first magnitude; those that appear something less, of the second magnitude; and so on as far as the sixth; which includes all the stars that are visible without a telescope. And though in a clear winter's night, when the moon does not shine, the stars seem to be innumerable, yet when the whole firmament is divided into signs and constellations, as it has been by the ancients, the number which can be seen at once, by the naked eye, is not above a thousand.

Since the invention of the telescope, indeed, the number of the fixed stars has been justly considered as immense; because the more perfect our instruments are, the more stars always appear to us; and it is therefore probable, that no limits can be set to their number or distances. The Galaxy, or Milky-Way, is one continued cluster of small stars, which combine to illuminate that part of the firmament, and diffuse such a shining whiteness through it; and in this portion of the heavens only, the telescope discovers to us that their number is indefinite.

"A broad and ample road, whose dust is gold,
And pavement stars, as stars to thee appear,
Seen in the Galaxy, that milky way,
Which nightly, as a circling zone thou seest
Powder'd with stars."_____

MILTON.

The immense distance of the fixed stars from our earth, and from each other, is, of all considerations, the most proper for raising our ideas of the works of God, and the vast extent of the creation. The star nearest to us, and consequently the largest in appearance, is Sirius, or the dog-star. Now the earth, in moving round the sun, is 190 millions of miles nearer to this star in one part of its orbit, than in the opposite one; and yet the magnitude of the star appears to be not in the least altered, or its distance affected by it. The celebrated Huygens carried his thoughts so far upon this subject, as to believe that there might be stars, at such inconceivable distances from our earth, that their light, though it is known to travel at the rate of ten millions of miles in a minute, has not yet reached us since the creation of the world.

The stars being at such vast distances from the sun, cannot possibly receive from him so strong a light as they seem to possess, nor any brightness sufficient to make them visible to us. For the sun's rays would be so scattered and dissipated

sipated before they could reach such remote objects, that they could never be transmitted back to our eyes, so as to render those objects visible by reflection. The stars, therefore, shine with their own native and unborrowed lustre like the sun: and since each particular star, as well as the sun, is confined to a particular portion of space, it is plain that they must be of the same nature with the sun.

Modern discoveries make it probable, that each of these fixed stars is a sun, having worlds revolving round it, as our sun has the earth and other planets revolving round him. For it is not to be imagined that the Almighty, who always acts with infinite wisdom, and does nothing in vain, should have created so many glorious suns, fit for so many important purposes, and placed them at such distances from one another, without proper objects near enough to be benefited by their influence. Whoever supposes that they were created only to give a faint glimmering light to the inhabitants of this globe, must have a very superficial knowledge of Astronomy, and a mean opinion of the divine wisdom: since many of the stars are so far from benefiting us, that they cannot be seen without the use of a telescope; and the Deity, by an infinitely less exertion of creating power, could have given our earth much more light, by means of one single additional moon.

Instead

Instead, therefore, of one sun, and one world only in the universe, as the unskilful in Astronomy imagine, that science discovers to us such an inconceivable number of suns, systems, and worlds, dispersed through infinite space, that our planetary system compared with the whole, appears but as a point or atom, and is almost lost in the immensity of creation. The outermost of our planets, notwithstanding, revolves round the sun in an orbit of near five thousand millions of miles in circumference, and some of the comets make excursions of ten thousand millions of miles beyond the orbit of Saturn; and yet, at that amazing distance, they are incomparably nearer to the sun than to any of the fixed stars; as is evident from their keeping clear of the stars, and returning periodically by virtue of the sun's attraction.

Since the fixed stars, therefore, are prodigious spheres of fire, like our sun, and at inconceivable distances from each other, as well as from us, it is reasonable to conclude that they are made for the same purposes with the sun; to bestow light, heat, and vegetation on a certain number of planets and satellites revolving round them. And, from what we know of our own system, it seems probable, that all the rest are with equal wisdom contrived, situated, and provided with accommodations for rational inhabitants. For although there is an infinite

E

variety

variety in those parts of the creation, which we have an opportunity of examining, yet there is a general analogy running through and connecting all the parts into one scheme, one design, one whole!

To conclude, in the words of an admired writer upon this subject; "What an august! what an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of suns, multiplied without end, and ranged all around us at immense distances from each other, attended by ten thousand times ten thousand worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these worlds peopled with myriads of intelligent beings, formed for an endless progression in perfection and felicity.

If so much power, goodness, and magnificence, be displayed in the material creation, which is the least considerable part of the universe, how great, how wise, how good must He be, who made and governs the whole!"

LETTER IV.

OF THE SYSTEMS OF PTOLEMY, TYCHO BRAHE,
AND COPERNICUS.

OF all the gifts and benefits which the Author of our nature has so plentifully bestowed upon mankind, those which consist in the improvement of the mind by arts and sciences are the most estimable. And I congratulate myself, when I consider that I am engaged, at present, in the highest of all possible pursuits, that of promoting and communicating those divine pleasures.

The unbounded view of nature, which I have laid open in my last letter, and the wonderful operations of the Deity in every part of this stupendous fabric, will not only ennoble the mind and strengthen the understanding, but is likewise calculated to answer a still more important purpose, that of laying a sure foundation for natural religion, and leading us, in the most satisfactory manner, to a knowledge of the great Author and Governor of the universe.

To study nature, is to search into his workmanship; where every step must lead us to that mighty power who prevails throughout, di.

rects and animates the whole. From the microscopic animalcule, which is indiscernible to the unassisted eye, to the great and unmeasurable luminaries of heaven, he is every where present. And whilst we perceive his wisdom and power thus equally displayed in the exquisite and just motions of the greatest and subtlest parts of the creation, we cannot but be excited and animated to correspond with the general harmony.

What noble and sublime ideas of this great Being, do we obtain from contemplating the vast diversity and variety of his works, which the cursory survey we have taken of them, imperfect as it is, affords us; and how is the mind enlarged and captivated by the astonishing scenes, and agreeable reflections which these enquiries continually present to us. That part of nature, which is the immediate object of the senses, is very imperfect, and but of small extent; but by the assistance of art, and the help of our reason, is enlarged till it loses itself in an infinity on either hand. The immensity of things on one side, and their minuteness on the other, carry them equally out of our reach, and conceal from us the greater and more noble part of physical operations. As magnitude of every sort, abstractedly considered, is capable of being increased to infinity, and is also divisible without end; so we find

find that, in nature, the limits of the greatest and least dimensions of things are actually placed at an immense distance from each other. We can perceive no bounds of the vast expanse in which natural causes operate, and can fix no border or termination of the universe; and we are equally at a loss when we endeavour to trace things to their elements, and to discover the limits which conclude the subdivisions of matter.

The objects which we commonly call great vanish, when we contemplate the vast body of the earth; the terraqueous globe itself is soon lost in the solar system: in some parts it is seen only as a distant star; and in the greater part is unknown, or visible only at certain times, by vigilant observers, assisted, perhaps, by instruments like our telescopes. The sun himself dwindles into a star. Saturn's vast orbit, and the orbits of all the comets, croud into a point, when viewed from numberless places between the earth and the nearest fixed stars. Other suns give light to illuminate other systems, where our sun's rays are unperceived, but they also are swallowed up in the immeasurable expanse. Even all the systems of the stars, that sparkle in the clearest sky, must possess but a small part of that space over which such systems are dispersed; since more stars are discovered in one constellation, by the telescope, than the naked eye perceives in the whole heavens.

And after we have risen thus high, and left all definite measures so far behind us, we find ourselves no nearer to a term or limit; for all this is nothing to what may be displayed in the infinite expanse, beyond the remotest stars that have ever been discovered.

And, in like manner, if we descend in the scale of nature, towards the other limit, we find a like gradation from minute objects to others inconceivably more subtle; and are led as far below sensible measures, as we were before carried above them, by similar steps which soon become hid to us in equal obscurity. From microscopic observations that discover animals, thousands of which would scarcely form a particle discernible to the naked eye; from the propagation, nourishment, and growth of those animals; from the subtilty of the effluvia of bodies, retaining their particular properties after so prodigious a rarefaction; from many astonishing experiments of the chemists; and especially from the inconceivable minuteness of the particles of light, that find a passage through the pores of transparent bodies in all manner of directions, it appears, that the subdivisions of the parts of bodies descend by a number of steps or degrees that surpasses all imagination, and that nature is inexhaustible on every side, the two extremes of great and small being equally removed from our comprehension.

Nor

Nor is it in the magnitude of bodies only that this endless gradation is to be observed. Of motions, some are performed in moments of time, others are finished in very long periods; some are too slow, and others are too swift to be perceived by us. So that wherever we turn ourselves, we are lost in an endless labyrinth; and find fresh reasons, at every step, to adore and venerate that Being, whose works are so various and hard to be comprehended.

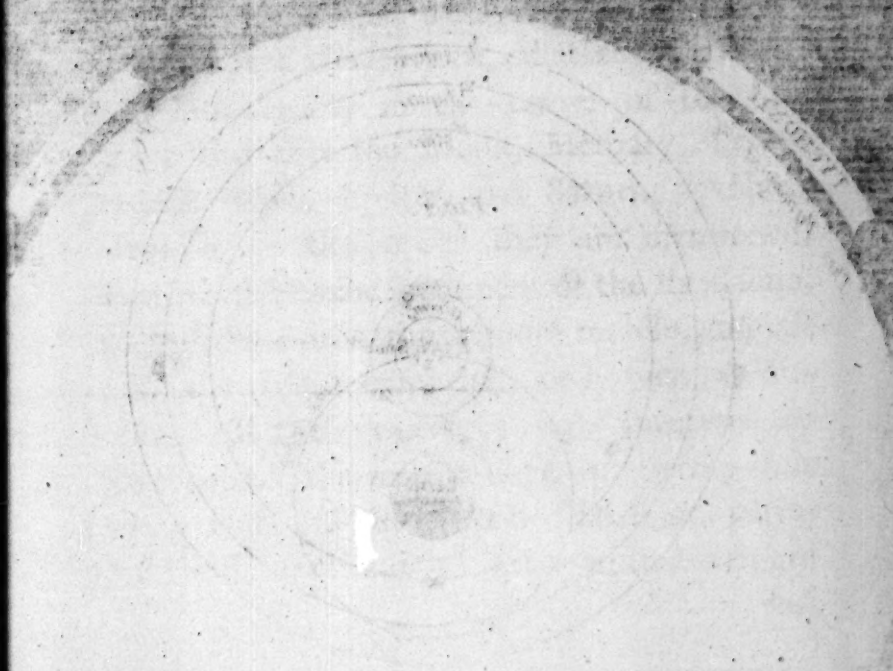
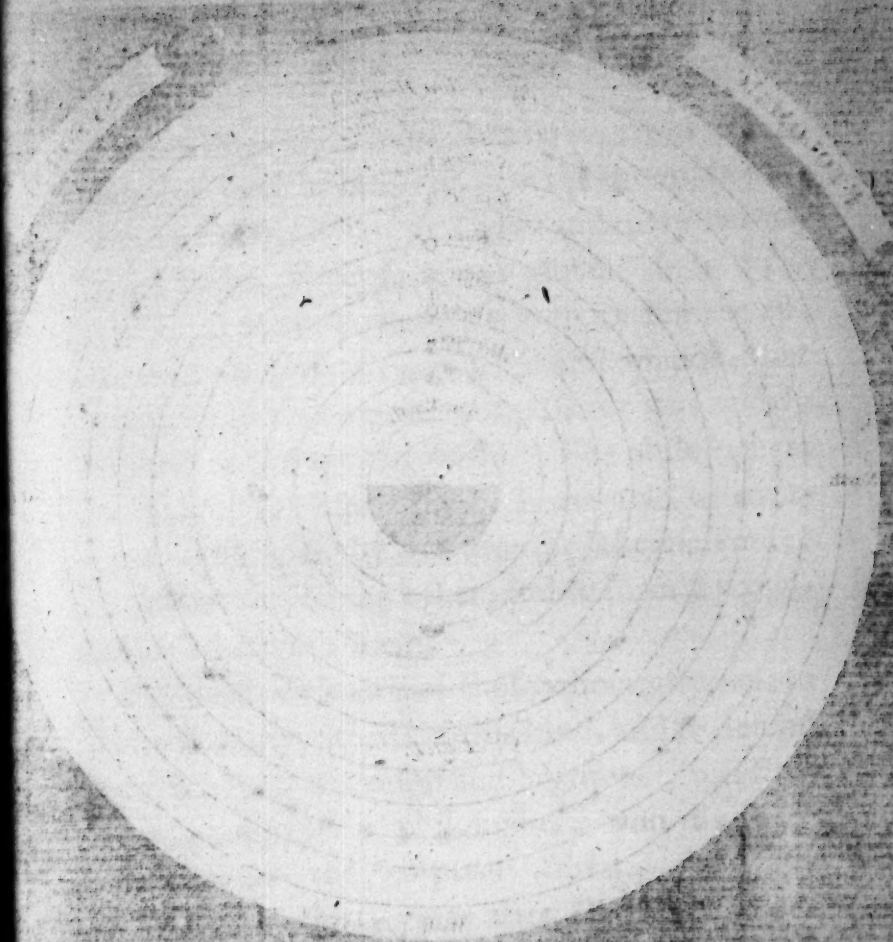
But it is now time to leave these pleasing digressions, and to give you some account of the different opinions of philosophers, concerning the situation of the heavenly bodies, or the place they possess in the universe. And in this enquiry you will not be surprized to find, that they are no less various and contradictory, than those relating to the figure and motion of the earth, as mentioned in a former letter. For mankind must have made considerable advances in astronomical learning, before they could so far disengage themselves from the prejudices of sense and popular opinion, as to believe in a doctrine so sublime, and remote from vulgar apprehension, as that which the moderns have now firmly established.

The beginnings of sciences, as well as of other things, are uncertain and obscured with fables: we collect, however, from several testimonies, that the true doctrine of the planetary mo-

tions was known in the world from the most early ages, and taught by some of the greatest and wisest men of antiquity. That admirable philosopher Pythagoras, who flourished near 500 years before Christ, was undoubtedly acquainted with this doctrine. But, from the accounts of his disciples and followers, it is evident, that it was not the result of his own observations; but that he had received hints of it from some more enlightened nations, who had made greater advances in the science.

It is most probable, that the doctrine was transplanted from the east by this great man, who spent two and twenty years in that part of the world, and scrupled not to comply with all the customs peculiar to the eastern nations, in order to obtain free access to their priests and magi, to whom almost all knowledge of arts and sciences was confined. And as he was a man of extraordinary qualities, and had an insatiable thirst for knowledge, so he seems to have been the most successful of any of the ancients in making himself acquainted with their philosophy.

Accordingly we find, that many of his followers had just notions of the planetary system; and not only taught that the earth moved daily on its own axis, and revolved annually round the sun, but gave such an account of the comets as is agreeable to modern discoveries. They also taught that every star was a world, having each
of



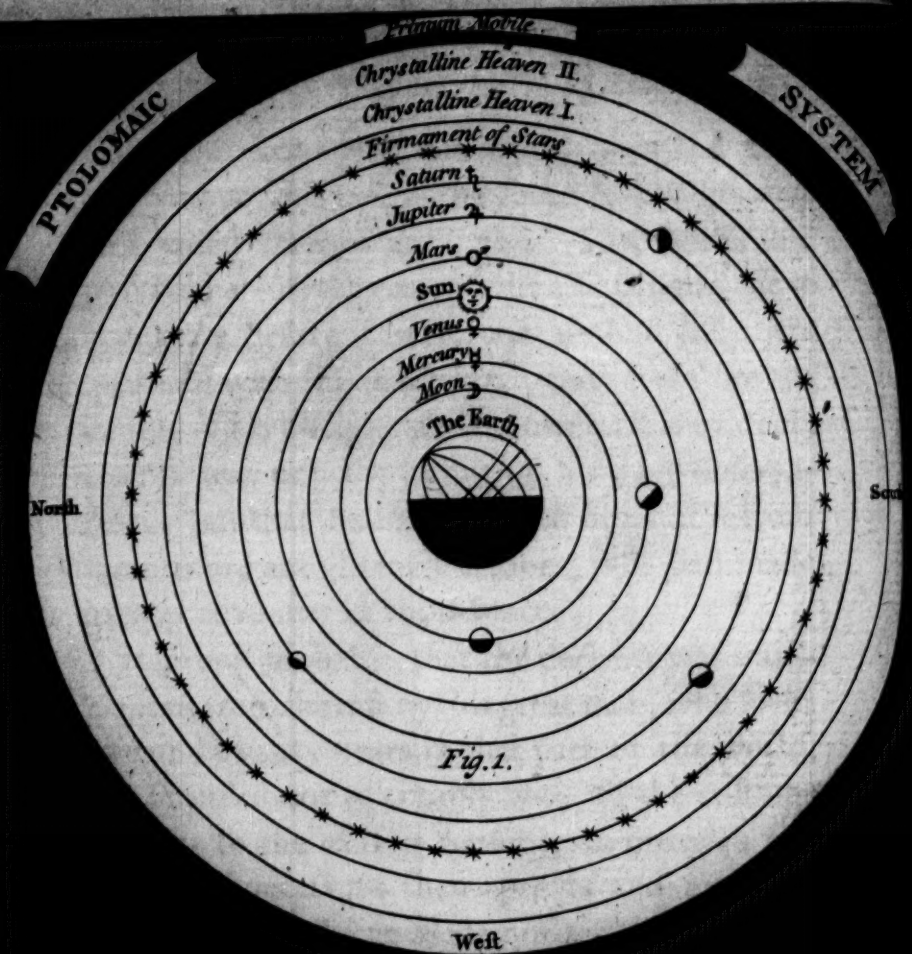


Fig. 1.

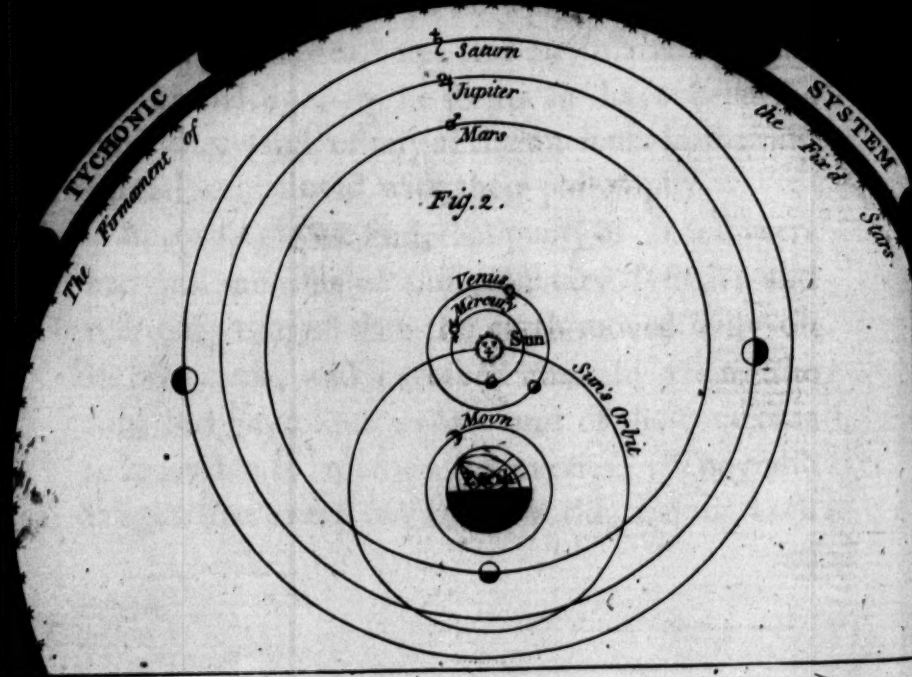


Fig. 2.

of them something corresponding to our earth, such as air and water; and that the moon, in particular, was inhabited by larger and more beautiful animals than those of our globe.

This system, however, was so extremely opposite to the prejudices of sense and opinion, that it never made any great progress, or was widely diffused in the ancient world. The philosophers of antiquity, despairing of being able to overcome ignorance by reason, set themselves to adapt the one to the other, and to form a reconciliation between them.

The most celebrated of those who undertook to establish an hypothesis of this kind, and to defend it with a shew of reason and argument, was Ptolemy, an Egyptian philosopher, who lived in the time of the emperor Adrian, about an hundred and thirty years after Christ. He supposed with the vulgar, who measure every thing by their own conceptions, that the earth was fixed immoveably in the center of the universe; and that the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn, revolved round it in the order they are mentioned. Above these was the firmament of the fixed stars, the crystalline orbs, the primum mobile, and last of all, the *cœlum empyrium*, or heaven of heavens. All these vast orbs were imagined to move round the earth once in twenty-four hours, and also in certain stated or periodical times, agreeably to their annual changes and

and appearances. Every star was supposed to be fixed in a solid transparent sphere, like crystal; and to account for their different motions, he was obliged to conceive a number of circles called eccentrics and epicycles, which crossed and intersected each other in all manner of directions. And if any new motion was discovered, a new heaven of crystal was formed to account for it. So that, in short, as Mr. Fontenelle observes, heavens of crystal cost him nothing, and he multiplied them without end, to answer every purpose.

This absurd system puts us in mind of a passage in the 8th book of Milton's *Paradise Lost*, where, speaking of the ridiculous dreams of visionary philosophers, concerning the nature and motion of the heavenly bodies, he says,

“ Or if they list to try
 Conjecture, he his fabric of the heav'n's
 Has left to their disputes, perhaps to move
 His laughter at their quaint opinions wide
 Hereafter, when they come to model heav'n
 And calculate the stars, how they will wield
 The mighty frame, how build, unbuild, contrive
 To save appearances, how gird the sphere
 With centric and eccentric scribl'd o'er,
 Cycle and epicycle, orb in orb.”

The embarrassment of these circles was so great, that Alphonsus, king of Castile, a considerable mathematician of his time, but not
 very

very religious, said that if God had called him to his council when he made the world, he could have directed him how to have done it in a much better manner. The thought favours too strongly of libertinism, but at the same time sufficiently exposes the confusion and absurdity of this hypothesis.

But independent of these considerations, this rude system was soon found incapable of standing the test of observation and experiment; and, notwithstanding the opposition of blind and zealous bigots, has long been rejected by all mathematicians and true philosophers. The planets, Mercury and Venus, are now certainly known not to include the earth in their orbits; and the comets move through the heavens in all manner of directions, so that they must infallibly have met with continual obstructions, and would long ere this have broken all these crystal spheres to pieces, and rendered them totally unfit for the purposes for which they were designed.

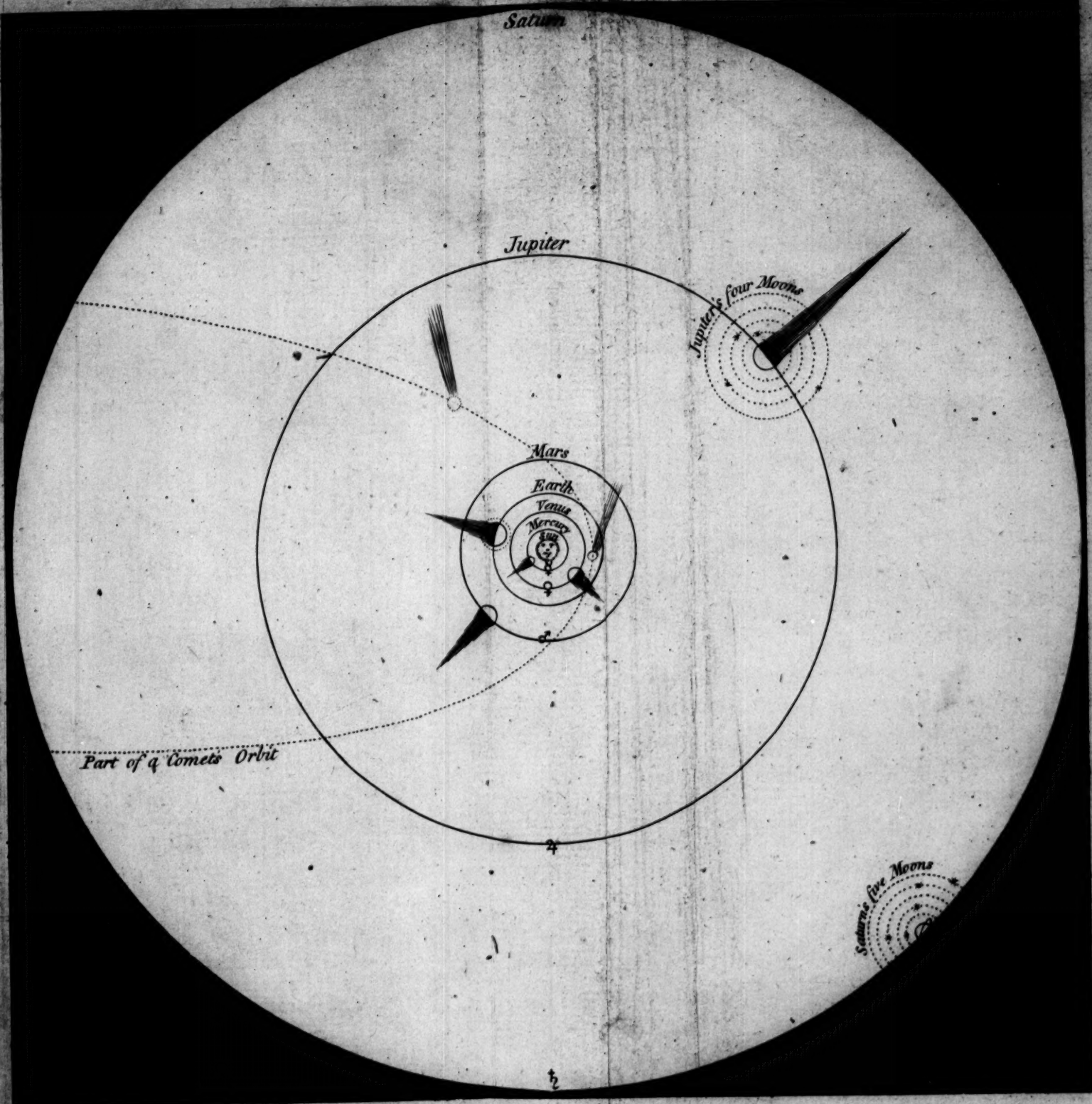
The contradictions and perplexities attending the Ptolemaic hypothesis, were so numerous and evident, that it was impossible they should ever be reconciled upon that supposition. But notwithstanding this, mankind were not easily induced to give up their darling prejudices, and embrace the truth, in whatever form she presented herself to them. Many early habits must be corrected, and vulgar prepossessions eradicated from

from the mind, before we can be brought to reckon the earth as one of the stars, and to consider this prodigious globe, which, of all things in nature, appears to be the most fixed and stable, to be carried round the heavens with the rapidity of 58,000 miles an hour.

To humour these prejudices, by keeping the earth still fixed in the centre, but at the same time to remove some of the most palpable absurdities attending that doctrine, was the design of Tycho Brahe, who attempted to establish a new system, and to account for the celestial motions by a more plausible hypothesis. This noble Dane, who flourished in the latter end of the sixteenth century, had furnished himself with an excellent collection of mathematical instruments, and, by that means, had made himself too well acquainted with the motions of the heavenly bodies, to imagine their center to be any where else than in the sun. He was struck with the beauty, simplicity, and harmony of the Pythagorean system, which Copernicus had lately revived; but out of respect for several passages of scripture, which seemed to contradict this doctrine, he set himself about to reconcile his learning with his faith; and, in order that the earth might remain quiescent, he supposed the sun, with all the planets, to be carried about it in the space of a year; whilst these, by their proper motions, revolved round the sun in their several periods.

Pl. I. fig. 2.

In



In this new system of Tycho's, there is some ingenuity, though but little conformity to truth and observation. For having rejected the diurnal rotation of the earth on its axis, he was obliged to retain the most shocking part of the Ptolemaic hypothesis, and to suppose that the whole universe, to its farthest visible limits, was carried by the primum mobile about the axis of the earth continually every day. But in this, however, he was abandoned by some of his followers, who chose rather to save this immense labour to the spheres, by ascribing a diurnal motion to the earth; and from this they were called Semi-Tychonics.

But though Tycho was not happy in establishing a new system, he yet did great service to Astronomy, by his diligence and exactness in making observations for a long series of years. Amongst other things, he discovered the refraction of the air, and determined the places of a great number of the fixed stars, with an accuracy unknown to the astronomers of former times. He likewise demonstrated, against the opinion which then prevailed, that the comets were higher than the moon; and from his observations on the moon, and the other planets, the theories of their motions were afterwards corrected and improved; so that for these services he will always be celebrated and esteemed by astronomers.

Arts

Arts and sciences, like kingdoms and states, have their various changes and revolutions ; at some periods shining out with uncommon lustre, and at others involved in ignorance and barbarity. Astronomy, after having flourished for a considerable time under the auspices of Pythagoras and his followers, was again neglected and obscured for many ages, so that the true system of the world seems to have been entirely forgotten. Instead of consulting the heavens, and collecting the history of nature, succeeding philosophers were ambitious of gratifying their own vanity, by inventing whimsical hypotheses, which had no conformity to fact and experiment. Solid orbs and epicycles were multiplied to answer every appearance, till the universe had lost all its native beauty in their descriptions, and seemed again reduced to a chaos by their unhappy labours.

It was about the middle of this century that Copernicus, a bold and original genius, adopted the Pythagorean, or true system of the universe, and published it to the world in the year 1530, with new and demonstrative arguments in its favour. Seized with a daring enthusiasm, he laid his hands on all the circles and crystal orbs of Ptolemy, and dashed them to pieces. And, with the same noble phrenzy, took the unwieldy earth, and sent her far from the center of the system, to move round the sun with the rest

rest of the planets; so that of all the celestial equipage, with which she had been formerly dignified, there only remained the moon to attend and accompany her in her journey.

Europe, however, was still immersed in barbarism and ignorance; and the general ideas of the world, were not able to keep pace with those of a refined philosophy. This occasioned Copernicus to have few abettors, but many opponents. Threatened by the persecution of religious bigots on the one side, and with an obstinate and violent opposition from those who called themselves philosophers, on the other, it was not without the greatest solicitations, that he could be prevailed upon to give up his papers to his friends, with permission to make them public. But, from continual importunities of this kind, he at last complied; and his book *de Revolutionibus Orbium cœlestium*, after being suppressed for more than six and thirty years, was at length published, and a copy of it brought to him a few hours before his death.

In this treatise he restores the ancient Pythagorean system, and deduces the appearances of the celestial motions from it in the most convincing and satisfactory manner. Every age since has produced new arguments in its favour; and notwithstanding the opposition it met with from the prejudices of sense against the earth's motion, the authority of Aristotle in the schools,

the threats of ignorant enthusiasts, and the terrors of the inquisition, it has gradually prevailed ever since, and is now universally received by all the learned throughout Europe.

Towards the end of the sixteenth century, and about the beginning of the next, those great men Galileo and Kepler, particularly distinguished themselves in the defence of this doctrine; and by means of the telescope, which was the admirable invention of that time, made many new and surprizing discoveries in the heavens. By applying this instrument to the planets, Galileo first observed, that the phases of Venus were like the monthly phases of the moon, and from thence inferred that she revolved round the sun as a center. He also proved the revolution of the sun on his axis, from the motion of his spots, and thence the diurnal rotation of the earth became more credible. The four satellites that attend Jupiter, in his revolution about the sun, represented likewise, in miniature, a just image of the great solar system, and rendered it more easy to conceive how the moon might attend the earth, as a satellite, in her annual revolution. In short, by his discovering hills and cavities in the moon, and spots in the sun, constantly varying, he proved, clearly, that there was not so great a difference between celestial and sublunary bodies as philosophers had vainly imagined.

From

From these discoveries, Astronomy began to assume a new form, and most of the celestial phenomena were soon accounted for, according to their real or physical causes. Des Cartes, Gassendus, Cassini, and Newton, employed themselves, with the utmost diligence, in improving and perfecting this science: and the last of these great men, in particular, has established the Copernican system upon such an everlasting basis of mathematical demonstration, as can never be shaken, but must last as long as the present frame of nature continues in existence.

LETTER V.

OF THE SYSTEM OF DES CARTES.

THE active mind of man is naturally fond of investigation ; and from contemplating effects, we are insensibly led to enquire into the causes that produced them. After having discovered the vast extent of the creation, and the order, regularity, and harmony of the celestial motions, our next reflections will be, how such a frame began at first to exist, and by what force those prodigious bodies are constantly driven round the sun, and detained in their orbits.

But to prosecute these researches with proper advantage, requires a free and unbiaſſed mind, invigorated with all the powers of genius and judgment. From the workmanship to trace the Workman ; and from viewing the grand machine of the universe, to discover the hidden springs of its motion, and the ſecret laws of its mechanism and contrivance, is, of all purſuits, the moſt ſublime and intereſting, and, perhaps, the higheſt pitch of knowledge which the human faculties are capable of attaining.

It muſt not, therefore, be conſidered as a matter of ſurpriſe, that, in the more early ages of the world, when ſcience was yet
in

in its infancy, and the mind of man enslaved and debased by ignorance and a barbarous superstition, a knowledge so exalted and refined should be but imperfectly understood, and but little cultivated.

The priests and magi of the east, who are supposed to have been the first masters of the sciences, involved all their notions in ænigmatical and allegorical representations; so that what was plain and simple, was rendered mysterious and doubtful; and mankind, instead of being made acquainted with nature, and the manner in which she conducts her operations, were amused only with absurd fables and chimerical conceits, which were so far from answering the purposes of instruction, that they served only to impede and retard it. To some of their most favoured disciples and followers they unveiled their mysteries, but the people in general were kept in darkness and the grossest ignorance.

From Egypt and Phœnicia philosophy travelled into Greece, and was there more generally cultivated and diffused, but in a manner equally unfavourable to instruction and improvement. The philosophers of those times, disputatious and obstinate, were more fond of victory than of truth; and whilst they contended only to shew their abilities, and to display a vain ostentation of learning, men were diverted from pursuing after real knowledge, and a talkative

philosophy was instituted, which was principally upheld by logical quibbles and sophistical subtilties, that had no relation to fact or experiment, the only sure foundations upon which any system of physics can possibly be supported.

Instead of searching into nature, men retired to contemplate their own notions; and, instead of tracing her operations, gave their imaginations full play; where they ought to have hesitated they decided; and where there was no difficulty they doubted. What was simple they divided, and defined what was plain; but in what was more intricate, the subterfuges of art were set up in opposition to nature, and captious science against common reason.

A considerable party of old, adopted that monstrous system, which, excluding the influence of a Deity, attempted to explain the formation of the universe from the fortuitous concurrence of atoms; and derived the ineffable beauty of things, and even life and thought itself, from a lucky hit in the blind uproar. One sect retained the passive and sluggish matter only, whilst others more refined, admitted active as well as passive principles, life as well as thought, and taught that every thing was governed by a supreme Mind. Some maintained, that there was no stability of essence or knowledge any where to be found, but that man was the measure of truth to himself in all things, and that
every

every opinion or fancy of every man was true. Whilst others, again, ran into the opposite extreme, and were so sceptical as to doubt even whether they doubted or not.

But to leave these, and a thousand other crude notions, which deserve no remembrance, we will now proceed to consider the more plausible hypothesis of a philosopher of modern times, who has attempted to explain the phenomena of nature by principles less exceptionable than those of the ancients; and has acquired such a reputation amongst his followers, as makes it necessary to examine his doctrine with more particular attention,

Renes des Cartes, a French philosopher, who was born in the year 1596, was the author of this new system, which has been so highly extolled, and considered by many, as the most extensive, and exquisite in its contrivance, of any that has yet been imagined. Endowed with a bold and elevated genius, he scorned to subject himself to the servile drudgery of observation and experiment, but attempted to unveil all the mysteries of nature at once; and thought it beneath him to offer any thing to the world, less than a complete and finished system.

In order to attain this grand purpose, he begins his Principia, by endeavouring to establish a clear and perfect idea of the existence and attributes of the Supreme Being; which he makes

to depend upon our inward conviction that such a being actually is ; and from this absolute and certain knowledge of the Deity, he attempts to deduce an explication of his works, that by this means, we may acquire the most perfect kind of science, which is that of deducing effects from their causes.

From the veracity of the Deity, he infers the reality of material objects, which are represented to us, as existing without us ; and, by placing the essence of matter in extension, concludes, that there can be no such thing as a vacuum, or space void of body or material substances ; but that all nature is absolutely replenished, and that there must be an universal plenum.

All self-evident propositions and axioms, are made to depend upon the mere will and arbitrary choice of the Supreme Being ; and, after explaining the formation of matter, and its division into different elements, he next proceeds to shew how the universe might have assumed its present form, and may be for ever preserved by mechanical principles.

To account for the motions of the celestial bodies, the sun is supposed to be placed in the center of a vast whirlpool of subtile matter, which extends to the utmost limits of the system ; and the planets, being plunged into such parts of this vortex as are equal in density with themselves, are continually dragged along with it,
and

and carried round their several orbits by its constant circulation. Those planets which have satellites, are likewise the centers of other smaller whirlpools which swim in the great one; and the bodies that are placed in them, are driven round their primaries in the same manner as those primaries are driven round the sun.

Now as the sun turns upon his axis, the same way that the planets move round him, and the planets also turn round their axes, the same way as their satellites move round them; it was imagined, that if the whole planetary region was filled with a fluid matter, like that before mentioned, the sun and planets, by a constant and rapid rotation on their axes, would communicate a circular motion to every part of this medium, and by that means drag along the bodies that swim in it, and give them the same circumvolution.

This, in few words, is the celebrated system of vortices, and the world of Des Cartes. The fabric, it must be confessed, is raised with abundance of art and ingenuity, and is evidently the produce of a lively fancy and a fertile imagination. But then, it can be considered only as a philosophical romance, which amuses without instructing us, and serves principally to show that the most shining abilities are frequently misemployed; and will always be found inadequate, to the arduous task of forming a complete system of

nature, which is not to be expected even from the labour of ages.

The method he has taken to establish the existence and attributes of the Deity, merely from any abstract notions which we can form of such a being, independent of his works, is certainly very improper and unsatisfactory. And the making of truth and falsehood, right and wrong, to be dependent on his will only, tends to weaken all science and confound its principles.

Whilst he supposes extension to constitute the essence of matter, he neglects solidity, and the inertia by which it resists any change in its state of motion or rest, which principally distinguishes body from space; and, for that reason, the doctrine of an universal plenum, deduced from this definition, is founded upon false principles.

That there is such a thing as a vacuum in nature, or a space void of body, may be demonstrated from a thousand experiments. By means of a pneumatic machine, or the air-pump, we can so far exhaust the air from a glass-receiver, that a guinea and a feather, being let fall together, from the top of the vessel, shall both descend equally swift, and come to the bottom at the same time: which evidently shews, that the air being taken away, there remains no other matter sufficient to cause any sensible resistance, or that in the least impedes or obstructs their passage.

Upon

Upon the supposition of an universal plentitude, all motion, indeed, is impossible. For whatever be the nature of this *materia subtilis*, whether dense or rare, the whole must be absolutely immovable and impenetrable; and for a body to pass through such a medium, would be more difficult than for it to pass through a sea of quicksilver, or a rock of adamant.

It was said, by many of the ancient philosophers, that nature abhors a vacuum; and by means of this absurd dogma, and many others of the like nature, they attempted to prove and illustrate the doctrine of an universal plenum, like that of Des Cartes. But this ridiculous notion of personifying nature, and giving her affections and passions, is too glaring an impropriety to require any formal refutation. And in nearly the same predicament, are most of the other arguments that have been used in defence of this doctrine. They are all sufficiently exposed, not only by the Torrecillian experiment, and the nature of pumps in general, but likewise from the most plain phenomena of the constant and free motion of bodies; as well those that are in the heavens, as those that are near the earth's surface, which come continually under our inspection.

The objections which may be brought against his vortices, or whirlpools, are also equally strong and irrefragable; and show clearly enough, the

the contradictions and absurdities which attend this hypothesis. For if these imaginary vortices, carried the planets from west to east, by means of their particular circulations, the comets which traverse those spaces in all manner of directions, from east to west, and from north to south, could never move according to any determinate law, as they would be constantly impeded and turned out of their course by so many contrary and opposite motions.

And besides, if it should be allowed, that the comets had never actually passed from east to west, and from north to south, yet nothing would be gained by this concession. For it is well known, that whilst a comet is passing through the neighbourhood of Mars, Jupiter, or Saturn, it moves incomparably swifter than either of those planets; and therefore cannot be carried round by the same bed of fluid matter, which is supposed to carry round these planets.

It has likewise been demonstrated by Newton, and others, that let the nature of these vortices be what it may, yet the circulations of the planets, in such a fluid, would never agree with the known laws of their motion, established by all the later astronomers, from repeated observations. But, admitting for a moment that this system of whirlpools was compatible with the phenomena of nature, and the laws of mechanics, yet their cause would be but little

little better; for no such whirlpools have ever yet been shown to exist. It is not sufficient that an hypothesis accounts for the phenomena; but it must be shown that it is founded in fact, and sanctioned both by reason and experience.

To sum up the whole, every one sees what must happen to several fluids circulating in contrary directions, and in opposition to one another. They would necessarily be confounded together; and instead of maintaining an order and harmony in nature, would form a chaos, and introduce eternal anarchy and confusion. This alone would at once have exposed the Cartesian system to the utmost ridicule, if a love of novelty, and an habitual disuse of free and impartial enquiry, had not universally prevailed in the world, and made way for its introduction.

This doctrine has been often altered, and variously mended, since it was first proposed by its author; and, for a hundred years together, many ingenious men have been making their utmost efforts to patch it up and support its credit. But the foundation is too faulty; and the whole superstructure so erroneous, that it were much better to abandon the fabric, and suffer the ruins to remain a memorial, to posterity, of the folly of philosophical pride and presumption.

It was upon the principles of the Cartesian philosophy, that Spinoza founded his system of
Atheism,

Atheism, and from thence attempted to defend all the absurdities which naturally attend such a doctrine. And though many of the followers of Des Cartes have endeavoured to show that his system is not in the least favourable to such notions, yet it must be owned that they have but ill succeeded. For if a void be impossible, and matter be infinite, it will evidently follow that matter must be necessary. But if matter be necessary, it must exist of itself, by an absolute necessity inherent in its nature, and antecedent to all things. Matter would therefore be God, and he who maintains these principles, ought, if he reasons consequentially, to admit of no other conclusion.

Leibnitz, the great and illustrious opponent of Newton and Clarke, draws, it is true, very different conclusions from this doctrine. From representing the universe as a machine that would proceed for ever, by the laws of mechanism, in the most perfect manner, and by an absolute and inviolable necessity, he concludes it to be a perfect work, or the best that could possibly have been made; and contends, that the contrary opinion is derogatory to the wisdom and power of the Supreme Being.

The origin of evil, which has perplexed and embarrassed the philosophers of all ages, he asserts to be perfectly reconcileable upon this system. Like Plato and Chrysippus of old, he maintains

maintains that it never could have been the aim, or first intention of the Author of Nature, and Parent of all good, to make men obnoxious to diseases, and other evils; yet, whilst he was producing many excellent things, and forming his work in the best manner possible, other things also arose, connected with them, that were inconvenient, and were not made for their own sake, but permitted as necessary consequences of what was best.

The perfection of the universe was, indeed, this learned author's darling theme. But after all he has said upon the subject, though it may perplex a cautious reader, yet it can never satisfy him. For is it not much more desirable that the Author of the world should be constantly acting in it, and cherishing it by his presence, than after having finished his work, that he should totally abandon it, and think it no further worthy of his notice or inspection?

It was fit that there should be, in general, a regularity and constancy in the course of nature, not only on account of its greater beauty, but also for the sake of intelligent agents, who, without this, could have had no foresight, or occasion for choice and wisdom in judging of things by their consequences; and therefore, no proper exercise for their reasonable faculties.

But

But though the course of nature was to be regular, it was not necessary that it should be governed by those principles which arise from the various motions and modifications of inactive matter, or by mere mechanical laws only; since it would then have been incomparably inferior to what it now is, both in beauty and perfection, and consequently far less worthy of its divine and ineffable Contriver.

LET.

LETTER VI.

OF THE DISCOVERIES OF KEPLER AND GALILEO.

DISTINGUISHED above other creatures, by the faculty of reason, and the superiority of his nature, man is still the slave of prejudice and opinion, prone to error, and subject to continual delusion. Truth and science advance by slow degrees; one age destroys the labours of another, whilst conjecture and hypothesis supply the place of argument and demonstration. Nature performs her operations constantly before our eyes, and has furnished us with the means of tracing their causes and connections; but the mind, debased by indolence, or bewildered by superstition, regards these astonishing scenes with indifference, and considers all attempts to investigate their causes, as the effects of a presumptuous and daring impiety.

From the time of Pythagoras to the sixteenth century, when the true system of the world was again revived by Copernicus, the vulgar opinion of the motion of the heavens, and the immobility of the earth, was generally received; and time, instead of discovering its fallacy, served only to

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strengthen and confirm it. To the authority of men of acknowledged reputation for their learning and talents, the example of ages was added; and thus was error transmitted from one generation to another, with additional prevalence. Plato and Aristotle were appealed to as the arbiters of every dispute, from whose authority there was no appeal; and when reason and argument failed, the aid of religion was called in to their support.

To dissent from the opinions of Aristotle, or those which his ignorant interpreters had given him, was looked upon as a heresy that called for the loudest anathemas of the church. And so venerable and sacred were those doctrines held, that whoever presumed to controvert them, was considered as an impious innovator, that attempted to remove the land-marks both of faith and reason. To his opinions, in all religious controversies, both parties appealed; from these the Papist supported all his absurdities, and the Protestant drew arguments for their refutation.

Error being thus established by time, superstition and prejudice, the face of nature was covered with a veil of awful obscurity, and the progress of useful knowledge effectually prevented. The highest ambition of some of the most eminent men of the age, was to prove the truth of that by sophistical arguments, which reason and science affirmed to be false. But
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such fantastical learning could not long prevail; time will always produce some lovers of truth, who will penetrate through clouds of error to attain it. After a long night of the most profound darkness, Copernicus again revived the true system of Pythagoras and his followers, and shewed it to be the only one which was agreeable to reason and observation.

But the greatest champion of useful learning that had hitherto appeared in the world, was Sir Francis Bacon, Lord Verulam, who by his superior knowledge and eminent abilities, overthrew the establishment of ignorance and error, and convinced the infatuated world, that opinions supported by the authority of Aristotle and antiquity, were not infallible. By clear incontrovertible arguments, supported by reason and science, he refuted their errors, and shewed that the only method of obtaining a true knowledge in philosophy was by observation and mechanical experiments.

It was now that men began to discern truth from falsehood, and disregarding hypothesis and conjecture, to investigate the works of nature from their effects and appearances. Matter and motion were observed to constitute the principal phenomena of the visible world, and as the properties and affections of these are the subject of mechanics, that science grew in esteem, and was

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cultivated by all the most eminent mathematicians in Europe.

By applying mathematical reasoning to mechanical experiments, Sir Isaac Newton established the truth of the ancient Pythagorean system; and upon this foundation raised the superstructure of that philosophy, which, whilst all other systems sink into ruins, and little more than their inventors names are remembered, will remain for ever firm and unshaken: for being once proved to be true, it must eternally remain so, as nothing can alter it but the utter subversion of the laws of nature, and the constitution of things.

The method of admitting nothing into philosophy, unconfirmed by experiment or demonstration, required too great a perseverance for the flighty imagination of those, who, contenting themselves with the semblance of truth, expatiated in the wilds of fiction. For a work of this kind, the genius and industry of a Newton was alone sufficient, who chose rather to acquire a little true knowledge of nature from practical investigation, than to aim at a general comprehension of all her operations, upon the weak foundation of probability and conjecture.

But in order that the genius of this extraordinary man may appear in its true light, it will be necessary to give you some account of the labours

bours of those, who, since the time of Copernicus, had been preparing the way, and laying the foundation for his discoveries and pursuits. And this information is the more necessary, as many persons, who have but a slight acquaintance with the progress of astronomical learning, are apt to entertain very erroneous opinions upon the subject. As the labours of many, are attributed to one Hercules, so, by a like exaggeration, Sir Isaac Newton is said to be the author of all the discoveries and improvements that have ever been made in this science. But as his merit is too great to stand in need of such extravagant additions, it will be proper to divest him of this false glory, by ascribing to him that only to which he has an undoubted claim.

The first founder of modern astronomy was Kepler: and if it be the privilege of genius to change received ideas, and to announce truths which had never before been discovered, he may justly be considered as one of the greatest men that had yet appeared in the world. Hyparchus, Ptolemy, Tycho Brahe, and even Copernicus himself, were indebted for a great part of their knowledge to the Egyptians, Chaldeans, and Indians, who were their masters in this science: but Kepler, by his own talents and industry,

industry, has made discoveries, of which no traces are to be found in all the annals of antiquity.

This philosopher was born at Wiel, in the province of Wirtemberg in Germany, on the 27th of December, 1571, and was one of the most zealous partizans for the Copernican system that had hitherto appeared. In 1596 he published a very large work upon the proportions and dimensions of the orbits of the planets, which coming into the hands of Tycho Brahe, he advised him to apply himself to observation, before he attempted to discover the laws of nature; and assured him, if he would do this, he would find more truth in his hypothesis than in that of Copernicus. He perceived the genius of Kepler, and wished for nothing more earnestly than to have him for his disciple.

I shall not enter into a detail of the reasons which are given by Kepler for arranging the planets according to the order of the five regular bodies, nor of the mysterious harmony which he finds between celestial and sublunary things. He was a man of a warm imagination, which led him into many absurdities; and it was the folly of that age, to mix sacred things with those that have not the least connection with them. He tells us in his *Mysterium Cosmographicum*, that he looked upon three grand things, which were at rest, as deserving his particular attention; the firmament

ment of the fixed stars; the sun, and the enormous interval that separates them; these appeared to him to be a symbolical representation of the Trinity; and the spherical figure of the universe, which comprehends the whole, he considers as an image of the Supreme Being, whose immensity envelops all things. Plato called God the eternal geometer; and Kepler, worthy to be the successor of so great a master, believed that certain properties of numbers and geometrical figures had a hidden analogy to all the operations of nature.

Besides entertaining a number of chimerical ideas of this kind, he had also a secret attachment to astrology; and in his treatise *De Stellâ Novâ*, has offered a very singular defence of this fallacious doctrine. He asserts, that all the great events and revolutions of the world have an intimate connection with the conjunctions of the planets, and accounts for their influence by comparing it with the action of objects upon our senses. "The stars," says he, "act upon terrestrial things in the same manner as light acts upon the eye, sound upon the ear, or heat and cold upon the sense and feeling." From this explication, which is one of the most ingenious that has yet been given, it is easy to perceive upon what foundation the dreams of astrologers are supported.

But from these absurd reveries, which were mostly the follies of his youth, he soon passed to

objects more worthy of his attention. His first works were only the amusements of his leisure hours; but in contemplating his powers, he found himself destined for much greater things. He was led, by an invincible impulse, to the study of philosophy; and no operation of nature ever attracted his notice, but he was immediately desirous of searching into its cause, and attempting its explication. His observations upon the nature of refraction, parallax, and many other subjects of equal importance, are sufficient proofs of his penetration and judgment; and from his uniting the science of optics with that of astronomy, we may easily judge of his genius and abilities.

In the true system of the world, as restored by Copernicus, the astronomer, having no longer a stationary situation upon our globe, is obliged to transport himself to the centre of the sun, and to observe the celestial motions from a point which is only accessible by the imagination. It was from this point that Kepler contemplated the spectacle of the heavens, and saw the fallacy of a doctrine, which all the astronomers before his time had considered as infallible. The apparent simplicity of nature in all her operations, had seduced them to imagine, that a circular and uniform motion of the heavenly bodies was a necessary consequence of this law. But this opinion, however reasonable it might seem to others, appeared



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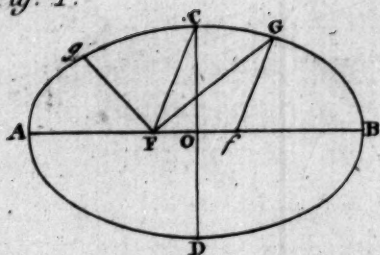


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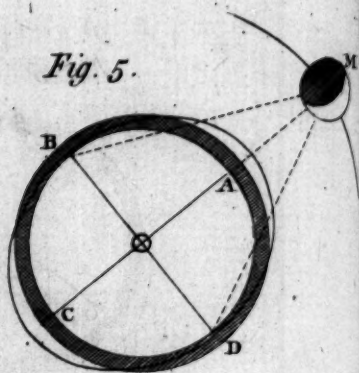


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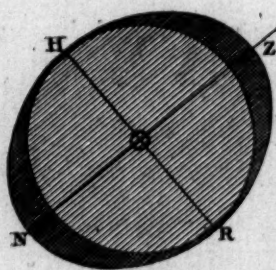


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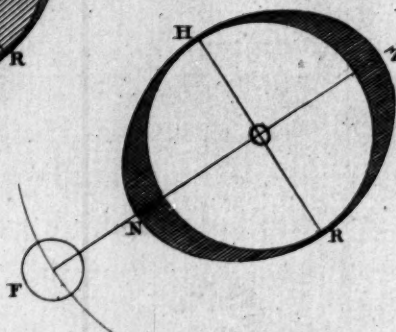
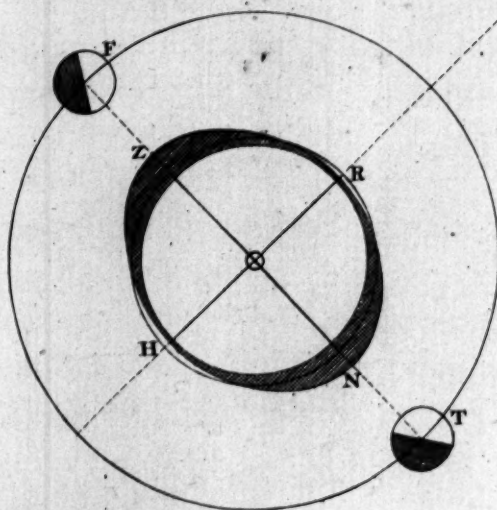


Fig. 8.



peared to him as an idle conjecture; and from the observations of Tycho, and his own industry, he soon proved it to be erroneous and ill-founded.

That the orbits of the planets were not circular, might, indeed, have been easily conjectured from many circumstances. Their conjunctions, oppositions, and other mutual situations, not returning again in the same time; and their distances from the sun appearing to be greater or less in different parts of their orbits, were sufficient indications of the fallacy of this doctrine. But so firmly were astronomers persuaded that their motions must be circular, that they attributed these irregularities to an optical delusion, and invented cycles and epicycles without number, to account for every appearance.

Kepler was the first who perceived, that all motion is naturally performed in a straight line; and that when a body moves in a circle, or any other regular curve, it must be acted upon by two forces, one that sets it in motion, and another that opposes this motion, and changes its direction. From these principles, and a number of calculations equally difficult and laborious, he proved, that the planets must revolve in elliptical orbits, the sun being placed in one of the foci; and that their velocities are such, that a line drawn from the sun to a planet, and supposed to

move with it, will describe equal areas in equal times.

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In order to illustrate this by a figure, let $A D B C$ be an ellipsis, whose transverse, or longest diameter is $A B$, and its conjugate, or shortest diameter $C D$; then the two foci $F f$ are points so situated, that if two right lines be drawn from them to any point G in the curve, the sum of those lines will always be equal to the transverse diameter $A B$. And if the sun be placed in the focus F , and a planet be supposed to revolve round him in the curve $B C A D$, it will move in such a manner, that a line drawn from it to the sun, will describe equal areas in equal times. That is, if the line $F G$, drawn from the sun F to the planet G , describes the area or space $B F G$ in a month, it will describe an area $G F g$ equally large the next month; and so on through its whole revolution.

The distance between the centre of the ellipse O , and one of its foci F , is called its eccentricity; and the two extreme points A and B of the transverse diameter, are called the apses. If the focus about which the equal areas are described, be at F , the point A , nearest that focus, is called the lower apsis, the point B the upper apsis, and the diameter $A B$ the line of the apses. When a planet, in revolving round the sun, is at its nearest distance from him, as in A , it is said to be in its perihelion; and when at its furthest

furthest distance, or at B, it is said to be in its aphelion the mean distance being F C. In like manner, when the earth is in its perihelium, the sun is said to be in its perigee; and when the earth is in its aphelion, the sun is said to be in its apogee.

But let us leave the further explanation of these terms for the present, and return again to Kepler. This excellent astronomer, having firmly established the law before-mentioned, proceeded to the consideration of another, of no less importance. He had happily conceived, that there might probably be some proportion between the times of the revolution of the planets, and their distances from the sun; and by prosecuting the enquiry, which this idea suggested, his success was equal to his most sanguine expectations. By calculations founded on a series of the most accurate observations, he discovered, that the squares of the times in which any two planets complete their revolutions in their orbits, are exactly proportional to the cubes of their mean distances from the sun.

To illustrate this rule by an example: Venus, for instance, revolves round the sun in 224 days, and the earth in 365; and the mean distance of the earth from the sun is ninety-five millions of miles. Hence, according to Kepler, as the square of 365 is to the square of 224, so is the cube of ninety-five millions of miles, to a fourth number, which

which is the cube of Venus's mean distance from the sun ; and if the cube root of this number be found, it will give about sixty-eight millions of miles for her real mean distance ; so that, by this rule, if the times of the periodical revolutions of the planets be known, and the mean distance of any one of them from the sun, the mean distances of all the rest may be determined by a simple proportion. And this rule is not only applicable to the planets, but it is also equally true with respect to their satellites or attendants ; the moons of Jupiter and Saturn are found to follow the same law in revolving round their primaries, as is observed by those primaries in revolving round the sun.

These are the discoveries by which Kepler enriched the science, and obtained an immortality of renown : but it must be observed, that he who had subjected the planetary motions to invariable laws, was unable, with all his penetration, to find out the reason of them. Nature, in carrying him thus far, had done enough at one time, and it was now necessary for her to repose herself before she produced a Newton. Among a number of ingenious guesses which he has made upon this subject, there are some as novel as they are singular. He considers the stars and planets as the inhabitants of ether ; that live and move in that element like butterflies in the air ; or as plants and animals that spring from the bosom of
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the earth, to embellish it by their existence, and afterwards render back, by death, the fecundity that nourished them.

That such extravagant dreams should be found on the side of such sublime truths, is, as Mr. Voltaire observes, a matter not to be wondered at; a man may be a great genius with regard to calculations and experiments, and yet make a very wrong use of his reason in other respects. There are minds that stand in need of geometry to support them, and fall when they endeavour to proceed of themselves. It must be remembered, however, to the honour of Kepler, that his errors were mostly those of a great mind; and that some of his conjectures were as grand and philosophical, as others were whimsical and absurd.

His hypothesis for ascertaining the different densities of the sun and planets, according to their distance from the center of motion, is an instance of his penetration and judgment that particularly deserves to be mentioned. He conceived that the heaviest bodies in our system, must be those which are placed nearest the sun; and as he was always desirous of rendering his ideas as familiar as possible, he illustrates them by the following easy example. The density of Saturn may be compared to that of a diamond; Jupiter to a loadstone; Mars to iron; the Earth to silver; Venus to lead; Mercury to quick-

quicksilver ; and the Sun to gold, which is the heaviest of all substances we are yet acquainted with. Excepting the density of the sun, this rule differs but little from the truth ; and though it was founded upon false reasoning, it was nevertheless a happy conjecture. The time was not yet come for philosophers to weigh the celestial bodies, and to estimate with exactness their different densities.

This great man, whose whole life was so gloriously employed in cultivating and improving the sciences, had his last days embittered by all the horrors of poverty and distress. A small pension, which was scarcely sufficient for his subsistence, was frequently withheld or unpaid ; and the trouble and vexation this occasioned him was so great, that it obscured his genius, and soon put a period to his existence. He died the 15th of November 1631, in the fifty-ninth year of his age, leaving nothing for his wife and children, but the glory of his name, and the fame he had so justly acquired : but as these were insufficient to relieve his own wants, they could afford but little comfort to a helpless widow and her wretched offspring, whose indigence is said to have been such, that they had not even the common necessities of life.

Whilst Kepler, in Germany, was tracing the orbits of the planets, and settling the laws of their

their motions, Galileo, in Italy, was meditating upon the doctrine of motion in general, and investigating its principles. This philosopher was born at Pisto, in the year 1564, and began his improvements in mechanics, by banishing from the science those ridiculous distinctions which had been made by Aristotle and his followers, between bodies light and heavy, motions natural and violent, rectilinear and circular. He shewed, both by demonstration and experiment, that, in a space void of air, all bodies whatever, fall through equal heights in equal times; and that a body impelled by two forces, acting in the direction of the sides of a parallelogram, will follow the direction of neither, but proceed in the diagonal, and describe it in the same time, as by the action of one of the forces alone it would have described one of the sides.

These principles he also found to be equally applicable to the motion of all kinds of projectiles whatever. A ball or shell being thrown from the mouth of a cannon, is under the influence of two forces, which, by their joint action, regulate its motion, and determine its direction: one of these forces is that of the powder, by which it endeavours to move continually forward in a straight line; the other is that of its weight, which inclines it to descend, and fall towards the ground; and from the composition of these two forces, Galileo demonstrated that
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the curve described by the ball would be that of a parabola. Tartolia had before remarked, without assigning any good reason for his assertion, that a ball would be thrown to the greatest distance, when the piece made an angle of forty-five degrees with the horizon; this rule was not only confirmed by Galileo, but extended still further, by his proving that at all angles equally distant from forty-five degrees, the range would be the same.

The next subject that engaged his attention, was the phenomenon of falling bodies, and the law of their acceleration. Every attentive mind must have observed that a stone, or any other heavy body, in falling from a certain height, acquires a greater velocity the nearer it approaches the earth; but before the time of Galileo, no philosopher had been able to ascertain the exact proportion of its celerity, in the different instants of its descent. He was the first who determined that the velocities are always proportional to the times; and the spaces passed through to the squares of those times: that is, in a double time, the body will have acquired a double velocity; in a triple time, a triple velocity, &c. and likewise, in a double time, the body will have run through a space four times as great as in a single time; in a triple time, through a space nine times as great, and so on.

Galileo considered nature as the sole agent of the Supreme Being ; and that sagacious observance of her operations, which first led him to this useful discovery, was the means of conducting him to another of equal importance. Being with some company in a room, where a lamp was suspended from the roof of the building, this spectacle, which was mute to the rest of the spectators, afforded him a subject of the most profound meditation. He observed that all the vibrations of the lamp, whether great or small, appeared to be performed in the same sensible time ; and from this circumstance, simple as it may seem, he is said to have discovered the isochronism of the pendulum ; and that a long pendulum moves slower than a short one, according to a certain invariable proportion ; by which means he obtained a new instrument for measuring short intervals of time with greater exactness than could be done by clocks, or any other method then in use.

About the time of these discoveries, which were afterwards so fruitful in the hands of Huygens and others, we may place the invention of the telescope ; an instrument so singular in its nature, that before its actual construction, the mind could not have conceived such a contrivance, or imagined it to be possible. A lucky incident is said to have effected, what philosophy might have sought for in vain : the children of one Zachariah

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riah Jansen, a spectacle-maker of Middleburgh in Holland, being at play in their father's shop, happened, by chance, to place a convex and concave glass in a such a manner, that in looking through them at the weather-cock of the church, it appeared to be nearer, and much larger than usual. The surprise they expressed at this circumstance, exciting their father's curiosity, he examined the same object himself, and finding what the children said to be true, improved the hint, by fixing the glasses upon a board, that they might be always ready for observation.

A discovery attended with so many obvious advantages, could not long be kept a secret; the news was soon conveyed to all the learned throughout Europe. Galileo was at Venice when he first heard of the invention; and being only informed, that by the combination of two glasses, the apparent magnitude of objects might be considerably augmented, he soon discovered the whole secret. Instead of the board employed by Jansen, he made use of a tube, and at his first essay produced an instrument which made the diameter of objects appear three times greater than to the naked eye. At his next trial he magnified the diameter of an object about eight times, and soon after this thirty times; which is nearly the greatest perfection, that this kind of telescope is capable of.

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Thus was Galileo, and, by his means, the human species, in possession of two new organs of power and perception; one for measuring small, and almost imperceptible portions of time, with ease and exactness; and the other for subjecting those things to our observation, which by their smallness or distance would otherwise have escaped the senses. Mr. Montucla, who has examined the subject with impartiality and judgment, has given the invention of the telescope to Jansen; and, from the strength of the evidence, it appears highly probable that he was the first who saw the effects that such an instrument would produce. But if he be the real author of an invention, who, from a knowledge of the cause upon which it depends, deduces it from principle to principle, till he arrives at the end proposed, the whole merit of the discovery is due to Galileo; the telescope in the hands of Jansen, was a rude instrument of mere curiosity, pointed out to him by chance; but Galileo was the first who constructed it upon principles of science, and shewed the practical uses to which it might be applied.

The discoveries he made, by means of this instrument, were as new as they were surprising. The face of the moon appeared full of cavities and asperities, resembling vallies and mountains: the sun, which had generally been considered as a globe of pure fire, was observed to be sullied

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by a number of dark spots, that appeared upon different parts of its surface; a great number of new stars were discovered in every part of the heavens; the planet Jupiter was found to be attended with four moons, that moved round him in the same manner as our moon moves round the earth; the phases of Venus appeared like the monthly phases of the moon; and, in short, every observation he made, furnished him with a new proof in favour of the Copernican system, and served to shew that there is not so great a difference between celestial and sublunary nature, as the philosophers of antiquity had vainly imagined.

Galileo was now in the seventieth year of his age, and but for the persecution of those who ought to have cherished and revered him, his life might have been as happy to himself as it was beneficial to mankind. In the midst of his researches and discoveries, which he prosecuted with the greatest assiduity, he was summoned before the tribunal of the inquisition, as a man of the most obnoxious and dangerous principles; and on the 22d of June, 1663, the following arret was pronounced against him by seven cardinals, who were appointed his judges. It is a curious specimen of catholic infallibility; and as I am indebted for it to a member of that community, I shall give it you in his own words.

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“ Soutenir que le soleil immobile & sans mouvement local, occupe le centre du monde; est une proposition absurde, fautive en philosophie, & hérétique, puisqu'elle est contraire au temoignage de l'écriture. Il est également absurde & faux en philosophie de dire que la terre n'est point immobile au centre du monde; & cette proposition considérée théologiquement, est au moins erronée dans la foi”. After this, the following abjuration was dictated to him, which he was obliged to sign. “ Moi Galilée, à la soixante-dixième année de mon âge, constitué personnellement en justice, étant à genoux, & ayant devant les yeux les saints évangiles, que je touche de mes propres mains, d'un cœur & d'une foi sincères, j'abjure, je maudis & je déteste les absurdités, erreurs, hérésies, &c.

For a venerable old man, who had enlightened Europe by his discoveries, to be seen upon his knees before an assembly of haughty, ignorant bigots, renouncing, by their compulsion, those truths which nature and his own conscience affirmed to be incontrovertible, was a spectacle that cannot be thought of without indignation and abhorrence. Cardinal Bellarmine, one of his judges, had before threatened him with the vengeance of the church, if he should presume to propagate his heretical opinions any longer,

either by discourse or writing; and as Galileo had not paid an implicit obedience to this mandate, he was now proceeded against as a despiser of civil as well as sacred authority, and was accordingly sentenced to be confined in the prison of the inquisition, during the pleasure of the inquisitors.

This sentence, however, was afterwards changed into the milder one of being confined in the small village of Acetri in Tuscany during his life. Here he pursued his studies with as much avidity as ever, and made several new discoveries and improvements in his favourite science; but soon after this, whilst he was engaged in his observations upon the libration of the moon, he was suddenly deprived of his sight, and the heavens being now shut upon him, the book of nature was no longer subject to his inspection. His age advancing, and his infirmities increasing, the grave at length received him from his persecutors; he was buried in the tomb of his ancestors; his disciples, who loved him in his life, honoured him in death; and his name was transmitted to posterity with the fame he had so justly acquired.

The celebrated geometer Viviani, who had been one of his most favourite pupils, shewed a zeal for the glory of this great man, that is without an example; the most tender and dutiful

ful child could not have a greater affection for his parent than he had for his illustrious master. He considered it as the pride of his life that he had been one of his last disciples; and when Lewis the XIVth gave him a pension, and appointed him one of the foreign associates of the Academy of Sciences at Paris, he built a house at Florence, and after paying a tribute of gratitude to the French monarch, erected a magnificent monument to his beloved master Galileo.

LETTER VI.

OF THE NEWTONIAN SYSTEM, AND DISCOVERIES.

IN all ages of the world, mankind in general have been nearly the same: the powers of the mind are various; but there are certain prescribed bounds which it is the lot of but few to pass. The multitude were certainly designed for manual labour and industry, and their minds are, by custom, made conformable to their employments. Intent upon the common concerns and business of life, they have but little leisure, and less inclination, for mental improvement. This is the wise designation of Providence. The earth must be cultivated to support its inhabitants: a general refinement would be as prejudicial as a general barbarity.

Humanity, however, has higher privileges. Arts and sciences, legislation and morals, are absolutely necessary to the due regulation and order of civil society. And that a knowledge of them may be properly distributed, the Author of Nature has, at different times, raised up some
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great and illustrious genius to enlighten and instruct us. In religion, our most momentous concern, he has condescended to give us a divine guide; and in every art and science, we have had preceptors of eminence proportionate to the importance of the subject.—Every thing bears the marks of omniscience: wherever we turn our eyes, we perceive a presiding intelligence, that informs and regulates the whole.

To enumerate the most shining characters of ancient and modern times, and to shew the discriminating excellence and utility of the several pursuits in which they were engaged, would be a matter of much difficulty, and foreign to our purpose. The subject upon which we are, at present, to employ our attention, is physical astronomy; and we are now to consider the genius and doctrines of a man, who, in his philosophical character, appears to have been endowed with superior faculties, in order to dissipate the mists of ignorance and error, and to lead us to a knowledge of those sublime truths, which the wisdom of ages had been unable to discover.

Sir Isaac Newton is the person to whom we owe these obligations, and who is henceforth to be considered as our only sure guide and instructor. He was born at Wollstrop in Lincolnshire, on Christmas-day 1642. His father was the reduced descendant of a noble family; but

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the glory of his son eclipsed all the splendor of hereditary titles and honours. Of his juvenile studies we have but little knowledge; he seems rather to have been an inventor than a student. None of his first attempts or essays have ever appeared. His march was that of a giant: he entered at once into the depths of science, and all his steps were those of discovery. It was on this account that Mr. Fontenelle applied to him the following idea of the ancients, concerning the unknown source of the majestic river that fertilizes *Ægypt*: Il n'a pas été permis aux hommes de voir le Nil foible et naissant.

Every science upon which this great man employed his attention, received a new form from his hands, and was carried to a degree of perfection unlooked for by the ancients. In the course of a few years he had destroyed the works of ages, and erected an edifice of his own, that will be as durable as the fabric of nature itself. Algebra, geometry, mechanics, optics, chronology, philosophy, and astronomy, began now to assume an unusual splendor and dignity, and by his improvements and discoveries, were rendered prodigiously more extensive and important. The method of Fluxions, in particular, was entirely his own invention; and this alone was sufficient to have made his name immortal. The exquisite subtilty of this doctrine is such, that the powers of the human mind

mind seem inadequate to a higher pursuit. Any thing beyond it, must be the science of pure intelligence.

From a genius like this, what had we not to expect? His account of the universe, and the laws by which it is regulated, is founded upon the most indubitable principles of reason, science, and observation. We are now no longer to wander through the intricate mazes of hypothesis and conjecture. Nature appears again in all her primitive simplicity. Newton has dissolved the chaos, and separated the light from the darkness. His inimitable work, *The Mathematical Principles of Natural Philosophy*, contains the true astronomical faith; and those who reject its doctrines are the worst of heretics, as they shut their eyes against the clearest of all light, Demonstration.

In order to give you as clear and familiar an idea as possible of the manner in which he has investigated the laws and causes of the celestial motions, I shall first begin with his speculations upon the gravity or weight of bodies, and relate, from the authority of his commentator and friend, Dr. Pemberton, the simple incident that is said to have given birth to them.

About the year 1666, or the twenty-fourth year of his age, he retired from Cambridge into the country, in order to avoid the plague, which,

which, at that time, raged with great violence; and sitting one day in the orchard, under a tree, an apple, by chance, fell upon his head, and caused him to enter into a number of reflections. The phænomena of falling bodies particularly engaged his attention; and pursuing the ideas that presented themselves to his mind, he carried his researches from the earth to the heavens, and began to investigate the nature of motion in general. Because there is motion, said he, there must be a force that produces it; but what is this force? That a body, when left to itself, will fall to the ground, is known even to the vulgar; but if you ask them the reason why it does so, they will think you either a fool or a madman: the circumstance is too common to excite their admiration, although philosophers are so much embarrassed with it, that they find it almost inexplicable.

Let us follow Newton, and examine this question a little. Does the cause of weight or gravity exist in the bodies themselves, or out of them? It seems natural to conclude, that the propensity which all suspended bodies have of falling to the earth, exists in the bodies themselves. When I take a stone, and let it drop from my hand, it falls immediately to the ground; and would fall still farther, if there was a hole in the earth, and nothing hindered its passage. And the same thing happens to all
other

other bodies, with which we are acquainted : there is not a material substance, either great or small, but what will fall towards the earth the moment it is disengaged, and free from all outward impediments.

In like manner it may be observed, that when a stone or any other body is placed upon a table, it presses the table with the same force, by which it would, if left to itself, fall to the ground. When a body is suspended at the end of a string, the force that pushes it downwards stretches the string, and if it is not sufficiently strong, will break it. And from these circumstances it is plain, that all bodies press with a certain force against those obstacles that support and hinder them from falling ; and this force is precisely the same with that, which in a free space would bring them to the ground.

The cause of this propensity in all bodies to fall to the earth, be it what it may, is called gravitation or attraction ; and when a substance is said to be heavy, we mean nothing more than the tendency it has to fall to the ground ; or the force by which it presses upon any other body that supports it. The weight and gravity of a body may, therefore, be taken for the same thing ; both the one and the other expresses the force by which the body is impelled towards the earth ; whether this force exists in the body itself, or out of it.

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With this property of bodies, obvious as it is, the ancients were very imperfectly acquainted. They believed that there were substances, such as vapours and smoke, that by their nature were light, and would for that reason ascend. This, however, we now know to be a mistake: there is no such thing as absolute levity. For in an exhausted receiver, or a space void of air, all bodies whatever, smoke or a stone, a guinea or a feather, fall to the bottom in the same time. Every substance, therefore, has gravity or weight: no distinction is to be made between bodies light and heavy: they have all a like propensity to fall to the earth, and their nature is the same.

Neither can there be the least doubt but that gravity is a sort of force: for whatever is capable of putting a body in motion is properly so termed. But in all forces there are two things particularly to be considered; the direction in which they act, and their intensity, or power. With respect to the direction of gravity, we are sufficiently assured, both from reason and experience, that a body in falling moves towards the center of the earth; or, which is the same thing, in a straight line that is perpendicular to its surface. The intensity, or power of gravity, is also to be determined from the weight of the body under consideration. Those which are the heaviest, or weigh the most, descend with the greatest force; and those that weigh the least,

least, with the least force: so that the weight of every body is always the just measure of its gravity, or the force by which it is made to fall towards the earth.

It may be asked, if the same body, being conveyed to several different places upon the earth's surface, will always have the same weight. Those who have superficially considered the subject, will certainly imagine this to be the case. By numberless experiments, however, the truth of which is not to be doubted, we are enabled to prove the contrary. The weight of a body under the Equator is less than at either of the Poles, and in every other situation it varies according to the latitude of the place. It is easy to perceive, that this difference is not to be discovered by means of a balance, or the scales which are usually employed in this business; because the weight, against which the body is opposed, is subject to the same variation. The difference may be determined by the vibrations of a pendulum; or, which is the same thing, by the force of gravity itself; for it has been observed, that the same body at London or Paris, falls swifter than under the Equator.

These are but the first links in the chain of Newton's ideas: let us follow him a little further.—The earth is a globe, and gravity acts perpetually in straight lines which pass through its center. Suppose a hole could be bored through the earth, and that a body was placed at the center,

center, what would be its weight? Evidently nothing: it would remain in the situation in which it was placed, unsuspended and unsupported. The force of gravity being always directed towards the center, it could have no propensity to move either way, and would, therefore, have no weight. For the same reason, if a body was thrown into this hole from the earth's surface, the force acquired, by its acceleration in falling, would carry it to the same distance on the opposite side, from whence it would again return, and continue to move backwards and forwards for ever, if the medium had no resistance.

Since, therefore, a body, when placed at the center of the earth has no weight, it will also follow that, in descending towards the center, its weight will be successively diminished; for it cannot be supposed, that the gravity of a heavy body changes immediately from a certain fixed quantity to nothing. It must evidently lose its weight gradually as it descends; this is not only a reasonable conjecture, but it admits of the most rigorous demonstration. Newton, by means of his geometry, was able to ascertain this gradual diminution of weight, and to calculate its precise proportion; which, at all distances below the surface of the earth, he found to be proportional to the distance from the center.

Having bored a hole through the earth, and made a voyage to the center, let us now ascend
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towards the heavens, and see what takes place there. We have here an equal force of reason and demonstration to prove, that a certain diminution of gravity, will likewise follow at different heights above the earth's surface. For since this power acts in straight lines, directed towards the center of the earth, these lines may be conceived to form an equilateral cone, of an unlimited length, the circular sections of which will be greater in area the further they are taken from the vertex. And as those lines constantly diverge, or become wider apart, the further they are produced, it is plain that the action of gravity must be weaker upon the same body at a greater distance than at a smaller one, on account of the power being more diffused. The proportion arising from this consideration, is the same as that discovered by Newton, who found that the gravity of bodies, above the earth's surface, continually diminished as the squares of their distances from the center increased: or, which is the same thing, that the forces are as 4 to 1, when the distances from the center are as 1 to 2; as 9 to 1, when the distances are as 1 to 3; and so on.

From these reasons, you will readily perceive that gravity is a certain force, which acts upon all bodies, and gives them a tendency to fall towards the center of the earth. And that this force, whatever it may be, acts most strongly upon the earth's surface; and
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that in ascending or descending, it suffers a continual diminution. How then does it appear, that gravity or weight is an inherent and necessary property of body. It increases or diminishes perpetually according to a certain proportion of the distance from the center. What is permanent and stable admits not of such different and various mutations. You see then that weight is not so necessarily connected with matter, as upon the first consideration of the subject you would naturally imagine.

These were probably Newton's first reflections upon the nature of falling bodies. We shall now see what use he made of them, in applying them to the celestial motions. He soon perceived that the force of gravity was not confined to the surface of this globe; it acts at the bottom of the lowest vallies, as well as at the tops of the highest mountains. Perhaps, says he, it extends as far as the moon, and is the means of retaining her in her orbit. The conjecture was happy; and by means of the sublime science he had before invented, he was presently enabled to prove its validity. A body acted upon by two forces at once, will follow the direction of neither. Imagine the moon, at the first moment of its creation, to have been projected forwards, with a certain velocity, in a straight-lined direction; as soon as it begins to move, gravity acts upon it, and impels it towards the center of the earth. The moon, under the influence of both these
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forces, neither proceeds directly forwards, nor falls directly downwards, but keeps a middle course, and moves round the earth in a curvilinear orbit.

The idea will be more fully illustrated, by attending to the motion of a shell, or any other projectile. A ball shot out of the mouth of a cannon, in a horizontal direction, does not fall to the ground till it has proceeded to a considerable distance. And if the ball be discharged from the top of a high mountain, it will fly still farther before it comes to the earth. Increase the velocity, and the distance will be augmented accordingly. And thus, in imagination, at least, we can suppose the ball to be discharged with such a velocity, that it will never come to the ground, but return again to the place from whence it set out; and so proceed on again, and circulate continually round the earth, in the manner of a little moon.

Newton did not stop here: he began to generalise the problem, and by means of his mathematics, soon came to this important conclusion. A body which moves in a curve, round a fixed point, by virtue of a force directed to that point, describes equal areas in equal times. This is a law of nature which had before been discovered by Kepler from observation. The supposition, therefore, that the moon is under the influence of such a force, is confirmed both by science and

experience; it is according to the pre-established order of things; and we have both Nature and Newton for our authority.

It was discovered by Galileo, that bodies projected through the air, with any force whatever, describe a curve which is called a parabola. This is true in theory, and would be so in practice, if it was not for the resistance of the medium through which the projectile moves. But the genius of Newton, finding itself now at its ease, extended this problem and made it more general. He no longer considered the falling body as having a limited distance; but regarding only the attraction of the earth, and the lateral uniform velocity of the projectile, he proved that it would move round the earth in an elliptical orbit, having the center of the earth for one of its foci. The falling body, in this example, may be considered as a moon, moving round the earth, or as one of the satellites of Jupiter or Saturn, moving round those planets; as the circumstances, in either case, are exactly the same. This law also, which he has mathematically demonstrated, was discovered by Kepler from observation.

That the moon is actually under the influence of gravity, and moves by means of that force, may be shewn as follows: Sir Isaac Newton has demonstrated, that if the moon was deprived of the impulse by which she has a tendency to move
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in a right line from west to east, and the central force only remained, she would fall towards our globe, and describe fifteen Paris feet in the first minute of her descent. And as the mean distance of the moon from the earth is sixty of the earth's semi-diameters, and the force of gravity increases as the squares of the distances from the center decrease, the gravity of the moon near the surface of the earth would, therefore, be 3600 times greater than at her present mean distance; so that, in this situation, she would describe 3600 times fifteen feet in a minute.

Now, if we suppose the force acting upon the moon to be the same with that which acts upon bodies near the earth's surface, it will follow, from the doctrine of Galileo, that the moon, which, at a small distance from the earth, would have described 3600 times fifteen feet in one minute, must have described fifteen feet in the first sixtieth part of that minute, or in the first second. And as we know from experiments, that all heavy bodies, near the earth's surface, fall fifteen Paris feet in the first second of their descent, they are therefore precisely in the same case with the moon, and both of them are governed by the same laws; for so exact a conformity, or rather such a perfect identity of effects, can only arise from an identity of causes.

These discoveries are, like the genius of their author, universal; but before we proceed any

farther, it will be proper to enquire a little into the nature of gravitation in general, this powerful agent, which produces so many astonishing effects. It has been shewn, that by the action of this invisible power, a stone is made to fall to the ground, the moon circulates about the earth, and the satellites of Jupiter and Saturn round the bodies of those planets. The Newtonian doctrine, which proves the truth of these laws, from mathematical principles, is called the System of Universal Gravitation, or Attraction. But what is this occult principle of sympathy and union, that gives life and motion to inanimate beings, and how does it act? The effects are visible, but the agent that produces them is hid from our senses. It eluded the search of Newton himself; he that soared to the utmost regions of space, and looked through nature with the eye of an eagle, was unable to discover it.

That there is, however, such a principle, is not to be doubted. To deny its existence, would be to deny the truth of facts, established both by experiment and demonstration. That two distant bodies will approach towards each other, without any visible agent, either drawing or impelling them, may be made manifest from a thousand instances. The loadstone and a piece of iron mutually attract each other; two cork balls,

balls, swimming in water, approach together and meet; and, in electricity, we have numberless experiments to shew, that several other bodies have the like propensity to unite and embrace each other. These bodies, it is true, act by particular laws, different from that of gravity; but they serve sufficiently well to illustrate the nature of that principle.

But lest these instances should be thought insufficient, we will clear the subject from further doubts, by mentioning a few experiments, which, independent of mathematical demonstrations, go near to shew the universality of this property. Let a circular piece of ice, of two inches and a half in diameter, be weighed against any other substance by means of a balance, till they are exactly in equilibrio: under these circumstances, let the ice be brought to touch the surface of some mercury, contained in a basin below; the ice will be so strongly attracted by the mercury, that it will require nine pennyweights eighteen grains, to be put into the opposite scale, in order to restore the balance, and overcome the adhesion resulting from this contact. And it is certainly not the pressure of the air that occasions this adhesion, for the effect is exactly the same when the experiment is performed in vacuo.

One experiment more, will give you a firm reliance in the truth of this doctrine. The

French mathematicians, who were sent out to measure the circumference of the earth, had observed that a large mountain in South America drew the plumb line out of its vertical direction; but as this was a business foreign to that in which they were engaged, they neglected to make the observations which were necessary to establish its validity. The Royal Society, however, from this and other considerations, were induced to prosecute the enquiry. Dr. Maskelyne, the astronomer-royal, was employed by them for this purpose; and from a series of observations which were made on the mountain Schehallien in Scotland, it was proved that, by the attraction of the mountain, the plumb line was drawn out of its vertical direction about six seconds of a degree. This is sufficient to put the matter out of all controversy. All bodies whatever attract, and are attracted.

Let us return again to Newton. The attraction of all bodies, says he, is in proportion to the quantity of matter they contain: the sun is the largest body in our system: he is therefore the emperor of the world, and the earth, planets, and comets, are his subjects. By virtue of his power they move round him in their several orbits, "and from his lordly eye keep distance due, aloof amid the vulgar constellations thick." Among the planets, also, there are several orders of

of nobility. The Earth, Jupiter, and Saturn, are the lords of their dominions, and have the satellites or moons for their attendants. They each move round their master, in obedience to his will, and are subject to the laws he imposes on them. Thus celestial and sublunary nature are the same; order and regularity result from seeming confusion, and subordination and dependence are to be seen in every part of the universe.

Sir Isaac Newton had made his discoveries in geometry, and laid the foundation of his two celebrated performances, the *Principia* and the *Optics*, when he was only twenty-four years of age. This circumstance is no less extraordinary than the discoveries themselves; and serves to countenance the idea of Mr. Fontenelle, who observes, upon this occasion, that if intelligent beings, of an order superior to man, make a progress in knowledge by certain gradations, they fly whilst we creep, and pass over, without notice, the intermediate steps, by which we slowly advance from one truth to another, which has a dependence upon it. "When we consider, says this ingenious writer, that, according to the doctrine of Newton, every single satellite of Saturn must gravitate towards the other four, the other four towards the fifth; all the five towards Saturn; and Saturn and all of them towards the sun, according to a particular law:

what an immense skill in geometry must have been requisite to unravel the intricacies of so many different relations. It was a daring attempt to undertake it; and one cannot perceive, without amazement, that from so abstracted a theory, formed of so many particular theories, and all of them perplexed with so many difficulties, conclusions should always arise exactly conformable to fact and experience. These are, certainly such instances of genius and penetration, that when taken in their fullest extent, the idea of the poet will scarcely be thought too extravagant.

Nature and Nature's laws lay hid in night;
God said, Let Newton be, and all was light.

POPE.

LET.

LETTER VII.

OF THE NATURE OF THE TIDES; OR THE CAUSE
OF THE FLUX AND REFLUX OF THE SEA.

IN my last letter I have unfolded to you the grand principle of attraction, and the manner in which it operates. We have seen the genius of Newton in the heavens, and travelled with him to the sun and the planets. Let us now descend, and follow him into the world of waters, through the depths of the ocean. By what power or cause is it, that this vast liquid body rises and falls alternately twice a day in a manner so constant and regular. The ancients considered it as one of the greatest mysteries in nature, and were utterly at a loss to account for it.

Aristotle, the great oracle of antiquity, is represented as having thrown himself into the sea, because he was unable to explain its motions; and when he was in India, with Alexander the Great, it is said that he wanted to follow the tide in its reflux, to see where it would go to. The story is sufficiently absurd; but not more so than the following one related of Kepler. He, in one of his reveries, considered the earth as a
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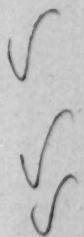
living being, and thought the flux and reflux of the sea the effect of its respiration: men, and other creatures, are insects that feed upon this animal; trees are the bristles on his back; and the water of seas and rivers a liquid that circulates in his veins.

Galileo, Descartes, and even Kepler, have, however, it is true, made better guesses in this business; but the first who clearly pointed out the cause of the phenomenon, and shewed its agreement with the effects, was Newton. To a genius like his, enterprise and discovery were recreation: the problem is only a particular case of a more general one, which he had before resolved. The moon he presently saw was the principal agent that produces these motions; and by applying his new principles of geometry and attraction, he soon shewed the manner in which they are effected. To follow him through all his calculations and enquiries, would be to perplex the subject instead of elucidating it. My wish is to give you the most interesting particulars, in as concise and popular a manner as possible. I shall therefore begin by describing the facts, and afterwards shew their conformity with the theory he has established.

The ocean, it is well known, covers more than one half of the globe; and this large body of water, although it is confined within certain limits,

mits, is found to be in continual motion. It ebbs and flows perpetually; and these alternate elevations and depressions are called the tides, or the flux and reflux of the sea. What connection these motions have with the moon, we shall see as we proceed; but, at present, it will be sufficient to observe that they follow a certain general rule. For example, if the tide be now at high-water-mark, in any port, or harbour, that lies open to the ocean, it will presently subside, and flow regularly back, for about six hours, when it will be found at low-water-mark. After this, it will again gradually advance for six hours, and then return back, in the same time, to its former situation; rising and falling alternately twice a day, or in the space of about twenty-four hours.

The interval between its flux and reflux, is, however, not precisely six hours, but about eleven minutes more; so that the time of high water does not always happen at the same hour, but is about three quarters of an hour later every day, for thirty days, when it again recurs as before. For example, if it be high water to day at noon, it will be low water at eleven minutes after six in the evening; and, consequently, after two changes more, the time of high water the next day, will be at about three quarters of an hour after noon; the day following it will be at about half an hour after one; the day after that
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at a quarter past two ; and so on for thirty days ; when it will again be found to be high water at noon, the same as on the day the observation was first made. And this exactly answers to the motion of the moon ; she rises every day about three quarters of an hour later than the preceding one ; and, by moving in this manner round the earth, completes her revolution in about thirty days, and then begins to rise again at the same time as before.

To make the matter still plainer ; suppose, at a certain place, it is high water at three o'clock in the afternoon, upon the day of the new moon ; the following day it will be high water at three quarters of an hour after three ; the day after that at half an hour past four ; and so on, till the next new moon ; when it will again be high water exactly at three o'clock, the same as before. And by observing the tides continually, at the same place, they will always be found to follow the same rule : the time of high water, upon the day of every new moon, being exactly at the same hour ; and three quarters of an hour later every succeeding day. Here is a perfect harmony of motions, which it would be absurd to impute to the mere concurrence of fortuitous causes. These alternate elevations and depressions of the ocean, are in such exact conformity with the motion of the moon, that, independent of all mathematical considerations,

rations, we should certainly be induced to look to her as their cause.

Neglecting, therefore, for the present, all such exceptions as affect not the truth of the theory, we will now proceed to shew, from Newtonian principles, that these phænomena are occasioned principally by the moon's attraction. For this purpose, let M represent the moon, O the center of the earth, and A, B, C, &c. different points upon its surface; and for the sake of making it more familiar, let us suppose the earth to be entirely covered by the ocean. Then, because it is the property of a fluid, for its parts to yield, and obey any force impressed upon them, it is clear that the moon M, acting upon the surface of the sea, at the points A, B, C, &c. will agitate the waters in those parts, and draw them towards her, by her attractive power. But the point A being nearer to the moon than the point C, the attraction at A will be greater than at C; and because the points B and D are at equal distances from the moon, the attraction at those points will also be equal; and so, at any other intermediate points, the attractive force will be different, according to their different distances from the moon.

From this example, then, it is sufficiently evident, that the attractive force of the moon, acting unequally upon different parts of the ocean, must occasion it to assume a different figure from what

PL. III.
fig. 5.

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what it would otherwise have, if there were no such unequal attractions. And as this attractive force is also greatest on the part of the ocean which lies immediately under the moon, the waters will of course flow constantly to that part, and be elevated or depressed, at different places, according as her situation changes with respect to those places. But the earth turns round on its axis, from the moon to the moon again, in about twenty-four hours and three quarters; and therefore the flux and reflux will be necessarily retarded, from day to day, about three quarters of an hour, which is agreeable to experience, and what we have before mentioned.

So far every thing is perfectly clear: the tides are evidently occasioned by the attractive force of the moon. But a circumstance the most singular, and difficult to conceive, remains yet to be explained; and this is, that they ebb and flow twice a day, or in the space of about twenty-four hours. It follows, from what we have already proved, that the moon, when she passes the meridian of any place, or is at her greatest height above the horizon of that place, will attract and elevate the waters which lie immediately under her: but how does it happen, that twelve hours afterwards, when she passes the meridian below the horizon, the waters, at the same place, are then also elevated. We know from experience, that whether the moon be in
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the zenith or nadir, the phenomenon is nearly the same: it is high water with us at the same time that it is high water with our antipodes; and this circumstance seemed, at first, so opposite to the nature of attraction, that some philosophers, who did not examine it to the bottom, thought it a sufficient refutation of that doctrine.

But the edifice of Newton is built upon a rock, and is not to be shaken by every idle wind that blows. It was ingeniously observed, upon a similar occasion, by his polite and candid opponent, the accomplished Marquis de Polignac, that what this great man asserts to be a fact must not be hastily rejected. I shall now shew you the necessity of attending to this precaution, in the instance before us. Let M represent the moon as before; O the center of the earth; and Z and N the zenith and nadir; or those parts of the surface which are the nearest to the moon, and the farthest from her; and, for the sake of perspicuity, let the earth, in this case, be considered as an entire fluid body. Then, because the point Z is nearer to the moon than the center O, it is evident that the water will be more strongly attracted at that point than at O; and of course the distance ZO will be increased. And, for the same reason, the center O being nearer to the moon than the point N, the water, about the point O, will be more strongly

Pl. III.
fig. 6.

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strongly attracted than at the point N; and the distance N O will likewise be increased. But since the distances O Z, O N, from the center to the circumference, are, by this means, increased, the waters, it is plain, will be elevated at both those points; because to increase the distance of any body from the center of the earth, is precisely the same thing as to elevate it. It appears, therefore, that the attractive force of the moon will raise the waters both at that point of the surface which is nearest to her, and at that which is farthest from her, at the same time, which is what was to be shewn.

Following this system, then, it is to be observed, that at any port or harbour which lies open to the ocean, the action of the moon will tend to elevate the waters there, when she is on the meridian of that place, whether it be above the horizon or below it. But the water cannot be raised at one place, without flowing from, and being depressed at another; and these elevations and depressions will obviously be the greatest at opposite points of the earth's surface. When the moon raises the waters at Z and N, they will be depressed at H and R; and when they are raised by her at H and R, they will be depressed at Z and N. And as the moon passes over the meridian, and is in the horizon twice every day, there will therefore be two tides of flood and two of ebb, in that time, at the interval of about
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six hours and eleven minutes each; which is also agreeable to experience, as has been before mentioned.

One great privilege of genius, seems to be that of considering difficult things under a point of view that renders them more simple and easy, and enables the mind to comprehend and follow them without effort. This felicity of conception was possessed by Newton in the highest degree: he always knew, in every case that required investigation, the proper mode of attacking the question. Geometry and mechanics were the weapons he used, and with these he soon conquered every difficulty. We have seen, in the present instance, how easily he removes objections, and reconciles apparent contradictions. The occurring of the tides at the same place twice a day, was made use of as an argument against the truth of his grand principle of attraction; but this, so far from being repugnant to that doctrine, he has shewn to be a necessary consequence of it.

Another seeming objection may also be removed with the same ease. From a slight consideration of what has been said, you would be led to imagine, that the time of high water at any place, would be when the moon is over the meridian of that place. This is, however, by no means the case: it is usually about three hours afterwards; and the reason of it may be

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shewn as follows. The moon, when she is on the meridian, or nearest to the zenith of any place, tends to raise the waters at that place; but this force must evidently be exerted for a considerable time, before the greatest elevation will take place; for if the moon's attraction was to cease altogether, when she has passed the meridian, yet the motion already communicated to the waters would make them continue to ascend for some time afterwards; and, therefore, much more will they ascend, when the attractive force is only in a small measure diminished. The waves of the sea that continue after a storm has ceased, and almost every other motion of a fluid, will illustrate this idea. A small impulse given to a body in motion, will make it move farther than it would otherwise have done. It is upon the same principle, that the heat is not the greatest upon the longest day, but some time afterwards; and that it is not so hot at twelve o'clock, as at two or three in the afternoon, because there is an increase made to the heat already imparted. Instead of its being high water then, when the moon is upon the meridian of any place, it will always be found to happen, as far as circumstances will allow, at about three hours afterwards; and the intervals between the flux and reflux, must be reckoned from that time the same as before.

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But is the moon, you will probably ask, the only agent concerned in producing the tides? Has not that prodigious body the sun likewise something to do in this business? The question is a very proper one, and naturally arises out of the subject. The sun has, no doubt, considerable influence in this case, but it is certainly much less than that of the moon. For it is not the entire actions of those bodies upon the whole globe of the earth, that is here to be considered, but only the inequalities of those actions upon different parts of it. The whole attractive force of the sun is vastly superior to that of the moon; but as his distance from the earth is near four hundred times greater, the forces with which he acts upon different parts of it, will be much nearer to equality than those of the moon, and consequently will have a less effect in producing any change of its figure. For it is to be observed, that if all the parts of the earth were equally attracted, they would suffer but little change in their mutual situations.

That this may be still more clearly understood, let it be considered, that though the earth's diameter bears a considerable proportion to the distance of the earth from the moon, yet this diameter is almost nothing when compared to the distance of the earth from the sun. The difference of the sun's attraction, therefore, on the

sides of the earth under and opposite to him, will be much less than the difference of the moon's attraction on the sides of the earth under and opposite to her: and, for this reason, the moon must raise the tides much higher than they can be raised by the sun. Newton has calculated the effect of the sun's influence in this case, and found that it was about three times less than that of the moon. The action of the sun alone would, therefore, be sufficient to produce a flux and reflux of the sea; but the elevations and depressions occasioned by this means, would be about three times less than those produced by the moon.

The tides, then, are not the sole production of the moon, but of the joint forces of the sun and moon together. Or, properly speaking, there are two tides, a solar one, and a lunar one; which have a joint or opposite effect, according to the situation of the bodies that produce them. When the actions of the sun and moon conspire together, as at the time of new and full moon, the flux and reflux becomes more considerable, and these are then called the Spring Tides. But when one tends to elevate the waters, whilst the other depresses them, as at the moon's first and third quarters, the effect will be exactly the contrary; the flux and reflux, instead of being augmented, will be diminished; and these are called the Neap Tides.

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But as this is a matter of some importance, it may be worth while to enter into a more minute explanation of it. For this purpose, let S represent the sun, Z H N R the earth, and F and C the moon at her full and change. Then, because the sun S, and the new moon C, are nearly in the same right line with the center of the earth O, their actions will conspire together, and consequently the water about the zenith Z, or the point immediately under them, will be raised to a greater height, than if only one of these forces acted alone. But it has been shewn, that when the ocean is elevated at the zenith Z, it is also elevated at the opposite point, or nadir N, at the same time; and, therefore, in this situation of the sun and moon, the tides will be augmented. And again, whilst the full moon F raises the waters at N and Z, directly under and opposite to her, the sun S acting in the same right line, will also raise the waters at the same points Z and N, directly under and opposite to him; and therefore, in this situation also, the tides will be augmented, their joint effect being nearly the same at the change as the full; and, in both cases, they occasion what are called the Spring Tides.

Plate III.
fig. 7.

Pursuing the illustration in the same way, let now F and T be the moon in her first and third quarters, and the rest as before. Then, since the sun and moon act in the right lines S O and F T,

Plate III.
fig. 8.

which are nearly perpendicular to each other, their forces will tend to produce contrary effects; because the one raises the waters in that part, where the other depresses them. The sun's attraction at R and H, will diminish the effect of the moon's attraction at Z and N; so that the waters will raise a little under and opposite to the sun at R and H, and fall as much under and opposite to the moon at N and Z, and of course the lunar tides will be diminished in that part. This respects only the moon in her first quarter at F; but the same reasoning will evidently hold, when applied to the moon in her third quarter at T; the sun and moon, still acting in lines that are perpendicular to each other, will produce the same diminution as before; and in both these cases they occasion what are called the Neap Tides. But it must be observed, that neither the Spring nor Neap Tides happen, when the sun and moon have the precise situations here mentioned; because in this case, as in all others, the actions do not produce the greatest effect when they are the strongest, but some time afterwards.

The effects of the disturbing forces of the sun and moon, depend likewise upon their respective distances from the earth, as well as upon their particular situations. For the less the distances are, the greater will be the effects. And, therefore, in winter, when the sun is nearer to the earth, the spring tides will be greater than in summer,

summer, when he is farther off; and the neap tides, on that account, will be less. And, for a like reason, as the moon moves in an elliptical orbit round the earth, and is nearer to us at some times than at others, the tides will, at those times, be greater, and at the opposite points of her orbit less. Some variations, likewise, take place in consequence of the different declinations of the sun and moon at different times. For if either of these luminaries were at the pole, it would occasion a constant elevation both there and at the opposite one, and a constant depression at the equator; so that as the sun and moon gradually decline from the equator, they lose their effect, and the tides become less; and when they are both in the equator, the tides of course become greater.

These are the principal phenomena of the tides; and where no local circumstances interfere, the theory and facts will be found to agree. But it must be observed, that what has been here said, relates only to such places as lie open to large oceans. In seas and channels, which are more confined, a number of causes concur, which occasion considerable deviations from the general rule. Thus, it is high water at Plymouth about the sixth hour; at the Isle of Wight about the ninth hour; and at London-bridge about the fifteenth hour, after the moon has passed the meridian. And at Batsha, in the kingdom of Ton-

quin, the sea ebbs and flows but once a day; the time of high water being at the setting of the moon, and the time of low water at her rising. There are, also, great variations in the height of the tides, according to the situation of coasts, or the nature of the streights they have to pass through. Thus the Mediterranean and Baltic seas have very small elevations; while, at the port of Bristol, the height is sometimes forty feet; and at St. Malo's it is said to be near a hundred.

Air being much lighter than water, and the surface of the atmosphere being nearer to the moon than the surface of the sea, it is plain that the moon will raise much higher tides in the air than she does in the sea: and on this account it should seem to follow, that the mercury in the barometer would sink considerably lower than at other times, when the moon passes the meridian; because her action on the particles of air, must, at that time, make them much lighter. But it must be considered, that in proportion as these particles are rendered lighter, a greater number of them is accumulated, till the deficiency of gravity has made up the height of the column; and as there is then an equilibrium, the pressure will evidently be the same as before; and consequently the mercury in the barometer, can in no respect be affected by means of these aerial tides.

LETTER VIII.

OF THE LATITUDE AND LONGITUDE, AND THE
METHODS OF DISCOVERING THEM.

IN almost all difficulties we have our resources; and such are the inventive powers of the mind, that there are but few things, which it is useful for us to know, but what some means have been devised for obtaining a knowledge of them. What can be more interesting to a person, in the course of a long voyage, than to be able to tell, at all times, upon what part of the globe he is? and how happy for him it is, that his wants have been anticipated, and the means of information provided for him. By the help of a few books, and a quadrant, he can not only inform himself of the situation he is in, but also how far he has travelled, what distance he has to go, and how he must direct his course to arrive at the place he designs to visit.

To determine these important particulars, nothing more is necessary, than to find the latitude and longitude of the places under consideration; for these being once known, by only turning to a common map or globe, the places themselves will

will be found by inspection. What is to be understood by these terms, and how they are applicable to the purposes mentioned, you will, no doubt, be anxious to enquire; and I shall endeavour to satisfy your curiosity to the utmost of my power. The subject is not less useful than it is curious. It is the very foundation both of geography and navigation; and in order that you may have as clear an idea of it as possible, we will begin with the first principles, and proceed gradually, step by step, to their application.

In the first place, then, as it is absolutely necessary for you to have a perfect conception of what is meant by the poles of the earth, the equator, and the meridians, I shall describe them in as familiar a manner as the subject will admit, and at the same time shew you their use and design. The poles are those two points which are at the extremities of the earth's axis; or where the imaginary line, round which it performs its daily revolutions, meets the earth's surface. That which is directed towards the most northern point of the heavens, is called the north pole; and that which is directed towards the most southern point, the south pole. So that they are diametrically opposite to each other, and always preserve the same relative situation.

Two poles turn round the globe, one seen to rise
 O'er Scythian hills, and one in Lybian skies;
 The first sublime in heav'n, the last is hurl'd
 Below the regions of the nether world;
 Where, as they say, perpetual night is found,
 In silence brooding on the unhappy ground:
 Or, when Aurora leaves our northern sphere,
 She lights the downward heav'n, and rises there;
 And when on us she breathes the living light,
 Red Vesper kindles there the tapers of the night.

DRYDEN'S VIRGIL.

And it is to be observed, that these two points have not been arbitrarily assumed by geographers and astronomers, to answer their particular purposes, for they are absolutely marked by nature upon the surface of the earth, and distinguished by her from all others. The nearer we approach to them, the more we find the earth becomes barren and inhospitable; so that, under the poles, the cold would be so excessive, that the country must be absolutely uninhabitable. Many attempts have been made to explore these remote regions, but they have all hitherto failed; and there is great reason to imagine that they are utterly inaccessible. The immense quantities of ice with which the ocean in those parts is continually covered, renders navigation impracticable, and any method of approaching them by land would be subject to still greater impediments.

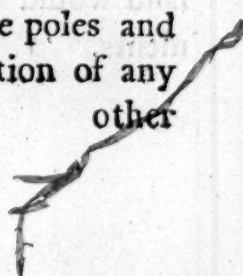
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From these considerations, you will be able to obtain a precise and determinate idea of the poles. Imagine now a circle to be drawn round the globe, exactly in the middle between these two points, and that circle will be the equator; so that the equator, properly speaking, is a great circle of the earth, which separates the northern from the southern hemisphere, and is every where at an equal distance from the two poles. And this circle is no less marked out by nature than the poles. The heat here is almost as intense as the cold is there; so that, for this reason, the ancients imagined the countries in both situations to be equally uninhabitable. This, however, we now know to be a mistake. Many places that lie directly under the equator, are found to be extremely populous, although the heat in general is almost insupportable.

And as five zones th' etherial regions bind,
 Five, correspondent, are to earth assign'd :
 The sun, with rays directly darting down,
 Fires all beneath, and fries the middle zone :
 The two beneath the distant poles complain
 Of endless winter, and perpetual rain :
 Betwixt th' extremes two happier climates hold,
 The temper that partakes of hot and cold.

OVID.

Having fixed the position of the poles and equator, it will be easy to form a notion of any other



other circles that can be drawn upon the globe. A meridian, for instance, is nothing more than a certain great circle, which is supposed to pass through the two poles, and to divide the eastern half of the earth from the western half. And because any place which is ever so little to the east or west of another place, may have a circle of this kind drawn through it, you will readily perceive that there may be as many meridians as there are places of different situations. The meridian of any particular place is also to be known, by its being that circle where the sun is always to be found at mid-day or noon, when he is at an equal distance both from the point where he rises, and the point where he sets.

These are the principal circles concerned in the present subject; and if they are properly understood, what follows will be found perfectly easy. The equator is represented as a boundary that separates the northern from the southern hemisphere; and the latitude of a place is nothing more, than its distance north or south from this circle. If the place lies in the northern hemisphere, it is said to have north latitude; and if it lies in the southern hemisphere, it is said to have south latitude: so that the latitude of any place will be greater or less, according as it is farther from, or nearer to the equator. And in order to estimate this distance, we conceive a meridian to be drawn through the place proposed;

posed; and by reckoning how many degrees of that circle are contained between this point and the equator, we are enabled to judge of the situation of the place with respect to its latitude.

Every circle is supposed to be divided into 360 equal parts, called degrees, and every degree into sixty equal parts, called minutes; so that, from these considerations, you will readily perceive what is to be understood by the latitude being expressed in degrees and minutes, and how the distance of any place from the equator is assigned by them.

If a place has ninety degrees of north latitude, that place will be evidently under the north pole; and if it has ninety degrees of south latitude, it will be under the south pole. In like manner, any place that is exactly in the midway between the equator and either of the poles, will have forty-five degrees of latitude, north or south, according to the hemisphere in which it lies: so that under the equator the latitude is nothing, but increases gradually as you advance towards either of the poles, where it is ninety degrees, or the greatest that it can be.

A great number of different places may also, it is evident, have the same latitude; for if a circle be supposed to be drawn through any point of the meridian, parallel to the equator, all the places that lie under that parallel will be equally distant from the equator, and consequently

quently must have the same latitude. It appears, therefore, that by knowing the latitude of a place only, we are not able to ascertain its exact situation. We can tell under what parallel it lies, and what is its distance from the equator; but other considerations are necessary to fix its precise position in that parallel, and to shew us how it is to be found upon a map or globe.

Before we can do this, we must know the distance of the place from a certain meridian, as well as its distance from the equator. But how is one meridian, you will say, to be distinguished from another? They are all equal between themselves, and so much alike, that no one of them bears any marks of preference above the rest. This is certainly true; and, for that reason, it depends upon our pleasure to fix upon any particular meridian, and to make that the principal one, to which all the rest are to be referred. Suppose, for example, that we take any remarkable place upon the earth, and consider the meridian which passes over that place, to be the first or principal meridian: this will then become distinguished from all the rest, and by noting the points where it cuts the equator, the others may be properly referred to it, by saying they are so many degrees of that circle distant from it.

The choice of a first meridian has been a matter of considerable embarrassment both to astronomers and geographers, and even yet they
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are not perfectly agreed in their determinations. The French make their first meridian to pass through the island of Fero, one of the Canaries; and the Dutch have fixed upon another of those islands, called Teneriffe, as the properest situation for this purpose. But the English, with more propriety, make their first meridian to pass over London, or rather Greenwich, on account of the Royal Observatory being at that place. This disagreement amongst the astronomers of different nations is not, however, to be considered as a matter of any great importance; for whichever is considered as the first meridian, the rest may be easily deduced from it, by marking the different points where they intersect the equator, and observing their difference.

The idea of making the meridian pass over the capital of a kingdom is a very natural one; but you will, no doubt, be curious to know why the islands of Fero and Teneriffe were fixed upon before all other places for this purpose. The principal reason seems to have been, on account of the westerly situation of these islands; for as they lie in the Atlantic ocean, between Europe and America, the first meridian being made to pass over this part of the globe, might then be considered as the western boundary of Europe. Besides this, the Dutch and Germans imagine the Pike of Teneriffe, on account of its being one of the highest mountains in the world, to be a place

place marked by nature for the purpose of a first meridian.

These reasons, however, are by no means satisfactory. The true position of the Canaries was not till very lately, determined; and it is absurd to make the first meridian pass through a place whose situation is unknown. Let us, therefore, follow our countrymen, and refer all the other meridians to that of London. This meridian, then, which is now to be called the first, cuts the equator in two opposite points, at the distance of 180 degrees each way. And as the equator is conceived to be the boundary which separates the northern hemisphere from the southern, so this circle may be conceived to be the boundary that separates the eastern hemisphere from the western.

The relation between these two circles, is also still farther observable: for as the latitude of any place is its distance north or south from the equator, so the longitude of any place is nothing more than the distance of its meridian measured on the equator east or west from the first meridian. If the place lies in the eastern hemisphere, it is said to have east longitude; and if it lies in the western hemisphere, it is said to have west longitude: so that the longitude of any place will be greater or less, according to its east or west distance from the first meridian. And in order to estimate this distance, we conceive a meridian to be drawn through the place proposed, and by reckoning how many degrees of

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the equator are contained between this and the first meridian, we are enabled to judge of the situation of the place with respect to its longitude.

This method is, however, subject to some ambiguities, which arise from considering the meridians as entire circles. Let us therefore consider them only as semicircles, drawn from one pole to the other. The thing will be exactly the same, and the difficulties, by this means, will be removed. Suppose now, we were to begin at that point where the first meridian cuts the equator, and divide the equator regularly each way into 180 degrees: the method of reckoning the longitude will then be perfectly easy and intelligible. If, for example, the meridian of any place cuts the equator at twenty degrees distance from the first meridian, the longitude of that place will then be twenty degrees, east or west, according to its situation with respect to the first meridian. From this consideration it is also evident, that the greatest longitude a place can have is 180 degrees; and that the longitude of any place lying under the first meridian will be nothing.

A great number of different places may also have the same longitude; for if a meridian be supposed to be drawn through any point upon the globe, all places lying under that meridian when referred to the equator, will be at an equal distance

distance from the first meridian, and consequently their longitude will be the same. It appears, therefore, that by knowing the longitude of a place only, we are not able to ascertain its exact situation, any more than we were from knowing the latitude only. We can tell under what meridian it lies, and what is its equatorial distance from the first meridian; but something more must be understood, before we can fix its precise position upon the globe. This knowledge is obtained, by finding both the meridian and the parallel of latitude of the place under consideration. So that for example, if a place be found to have twenty degrees of north latitude, and thirty degrees of east longitude, the intersection of the meridian and parallel will give the true situation of the place proposed.

But it is not the situation of towns and provinces only that we are so anxious to determine: this knowledge, though very important, may be still farther extended. In travelling by land, we are subject to few inconveniencies; but the calls of ambition, business and pleasure, have exposed men to new dangers. When the discovery of the compass invited the voyager to quit the consolatory sight of his native shore, and to venture himself upon an unknown ocean, that knowledge, which he might have thought but of little consequence before, became now a matter of absolute necessity. Floating in a frail vessel, upon an uncertain abyss, he has consigned him-

self to the mercy of the winds and waves, and knows not where he is : an uniform simultaneous plane, and an uninterrupted horizon, is all that he sees around him. The compass will direct him in his course, but it shews him neither the coasts he has left behind, nor those he endeavours to find.

In this situation of danger and distress, having no other resource, he applies to the heavens for assistance : he sees the stars, which he saw in his native country, and these are his only friends. Being fixed and immoveable, their situations are known ; and if the meridian altitude of any one of them above the horizon be found by a quadrant, it will shew him the latitude of the place, or what distance he is from the equator. But as many places have the same latitude, this only informs him that he is somewhere in a certain circle drawn parallel to the equator. To tell exactly in what part of this circle he is, he must find the distance he has travelled, or the difference of longitude, and determine the meridian that cuts the parallel in the place occupied by his vessel.

The latitude of a place is easily discovered, but the longitude is a subject of the utmost difficulty. Many methods have been devised for this purpose, which are sufficiently accurate upon land ; but at sea, where precision is most wanted, they are least to be depended upon. The question is so intimately connected with
trade

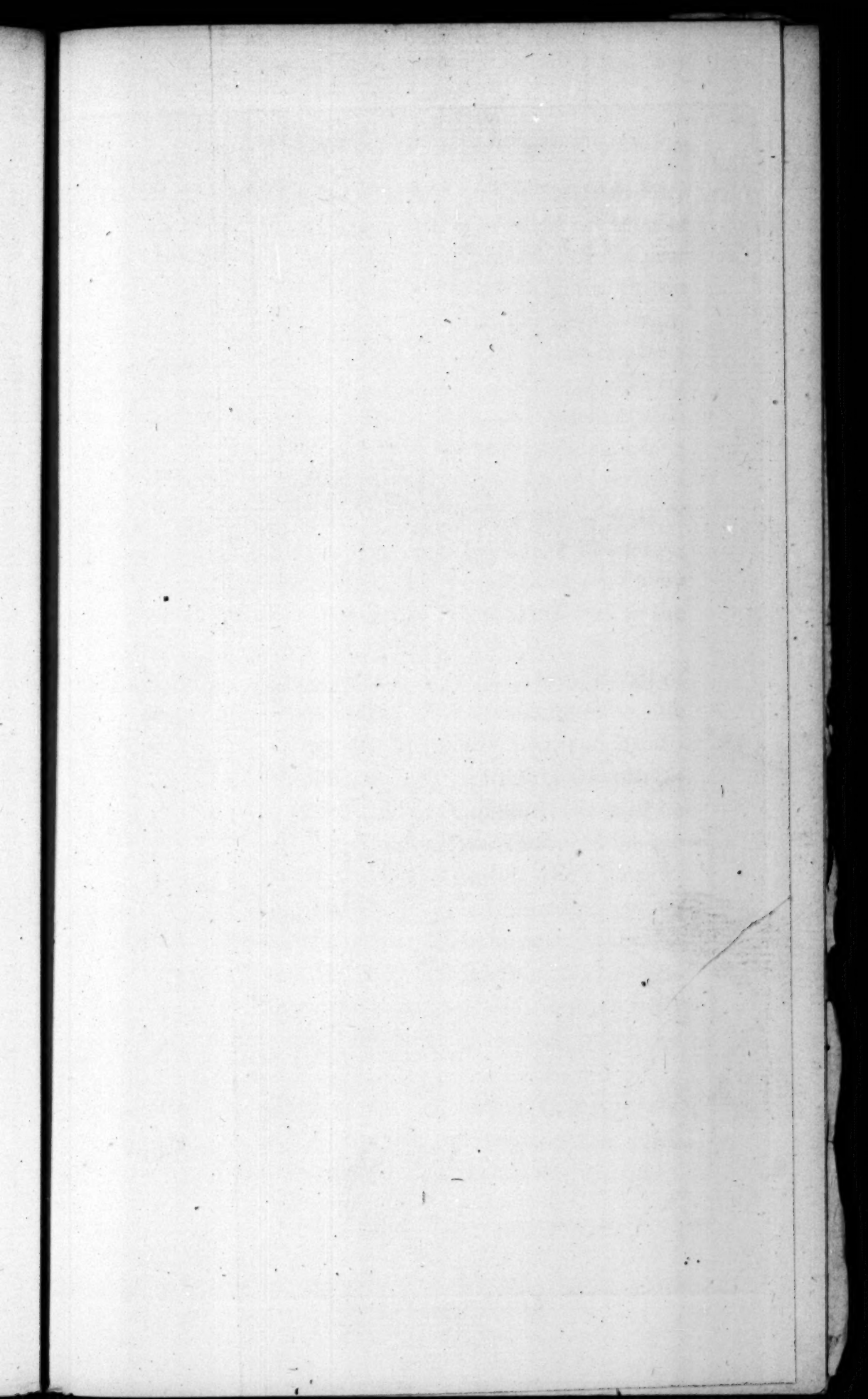


Fig. 9.

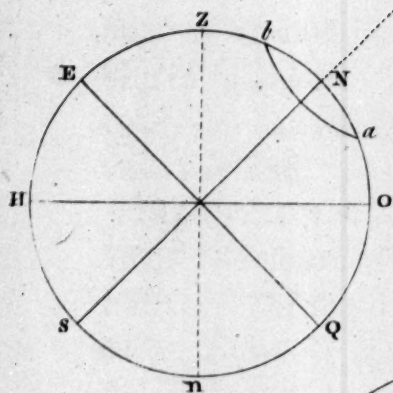


Fig. 10.

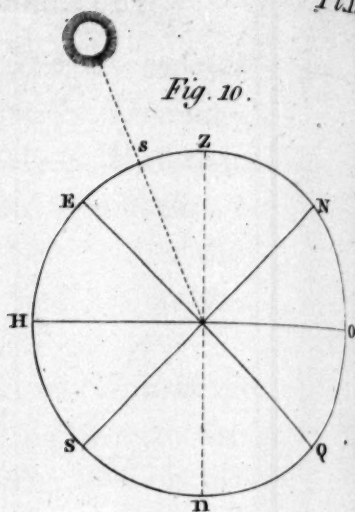


Fig. 12.

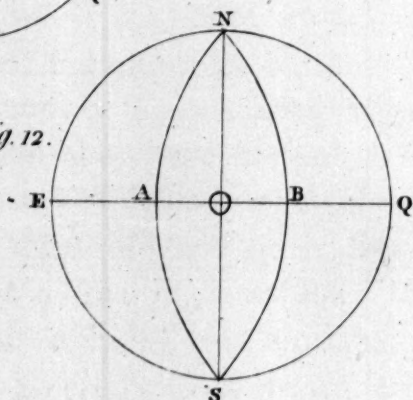


Fig. 11.

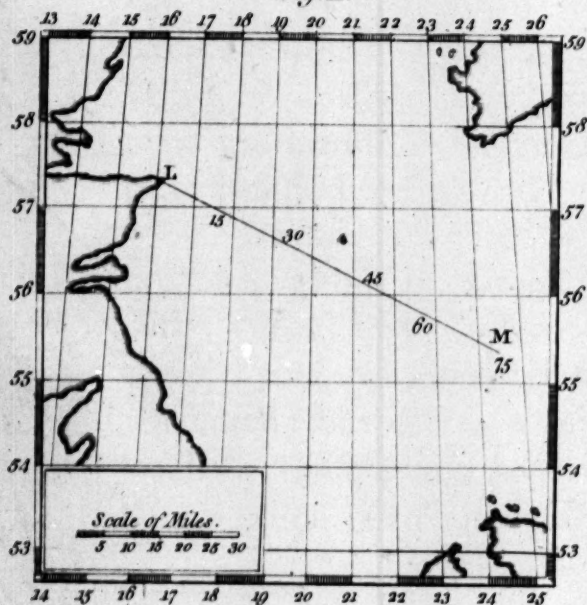
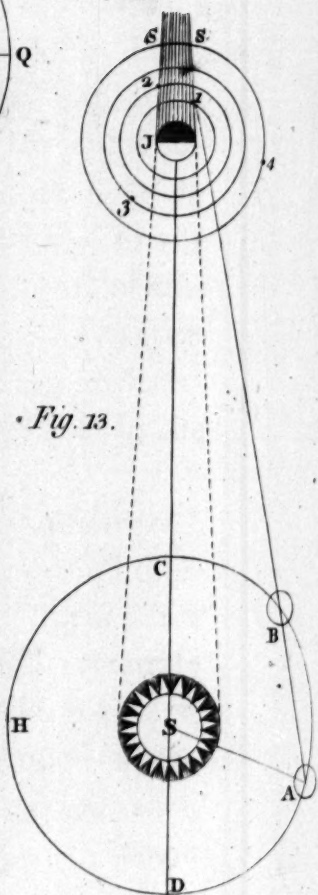


Fig. 13.



trade and commerce, that princely rewards have been offered for an easy and accurate solution of it. By an act of parliament, passed in the year 1714, the English government offered 20,000 pounds reward to any person who should discover a method for finding the longitude of places at sea, within thirty miles, or half a degree of a great circle: 15,000 pounds if it came within two-thirds of a degree, and 10,000 pounds if it came only within a degree of the truth. Such a liberal encouragement induced the learned of all nations to attempt this important discovery, which now became doubly interesting, both by the honour and profit it would procure the inventor.

I shall not perplex you with a long detail of all the methods invented by astronomers for this purpose, as they are frequently involved in abstruse calculations, which you would find both tedious and unintelligible. A general idea will be best obtained by considering those only, which are the most simple and easy; and if these be properly understood, it will not be difficult for you to comprehend the principles upon which they are all founded. We will first begin with the latitude, and show the means which have been used to discover the distances of places from the equator.

In this enquiry, the first method that suggests itself, is that of finding the height of the pole. This point is immoveable in the heavens, and as

it is found to be elevated or depressed according as we are farther from, or nearer to, the equator, it becomes, by that means, a criterion by which we can judge of our distance from that circle. Supposing ourselves, therefore, to be in the northern hemisphere, we will take this point for our guide, and endeavour to find the latitude of the place. The star, usually called the north pole, is not exactly in the north point of the heavens; but, for the sake of illustrating the subject, we will suppose, for the present, that it is, and see what would follow from its having this situation.

Pl. IV,
fig. 9.

Let $N\bar{S}$ be the axis of the earth, $E\bar{Q}$ the equator, and Z the zenith, or place of observation: then since ZO , the distance of the zenith from the horizon, is ninety degrees; and NE , the distance of the pole from the equator, is also ninety degrees; the arc OZ will evidently be equal to the arc NE ; and if the arc NZ , which is common to them both, be taken away, the remainder ON will be equal to the remainder ZE ; but ON is the height of the pole above the horizon, and ZE is the latitude of the place, or its distance from the equator; and therefore, if the height of the pole above the horizon be taken by means of a quadrant, or any other instrument proper for the purpose, it will always give the latitude of the place where the observation was made. Thus, the height of the north pole at London is found to be about fifty-one degrees,

degrees, thirty-two minutes; and therefore this is the latitude of the place, or its distance north from the equator.

But as the pole star is not exactly in the north point of the heavens, let some other star be taken that is about eight or nine degrees from that point, and find, with a quadrant, its greatest and least altitude, in the same manner as before. Then, as the star moves in a small circle round the pole, the time between the observations is about twelve hours, it is evident that, if the least of the two altitudes be added to half their difference, it will give the height of the pole, or the latitude of the place required. For, let b and a be the two positions of the star at its greatest and least altitudes, and N the true north point of the world; then, since b and a are diametrically opposite to each other, and N is exactly in the middle between them, it is plain that if Oa , the least altitude, be added to aN , half the difference of the altitudes, it will give ON , the height of the pole above the horizon; which, as was before shewn, is equal to ZE , the latitude of the place of observation.

PI. IV.
fig. 9.

This method, however, is liable to some exceptions; and as the same thing may be done by taking only a single altitude of the sun or a star, it is usually preferred in practice to the former. The problem admits of several cases, according to the situation of the observer; but as they are

all equally easy, an explanation of one of them, will be a sufficient elucidation of the whole.

Pl. IV. Suppose then, that a spectator at Z, sees the sun,
 fig. 10. at noon, over the point S, and finds, with a quadrant, the meridian altitude H S; then, if this altitude be taken from H Z, or ninety degrees, it will give the zenith distance Z S; and the zenith distance Z S, being added to the declination of the sun S E, will be the latitude of the place required.

The sun's declination, is his distance north or south from the equator; and as this may be found in the Nautical Almanac, ready computed for the noon of every day in the year, the latitude may always be obtained from it, without any trigonometrical operation whatever. Thus, for example, suppose that at some unknown place in the Western Ocean, the sun's meridian altitude was observed to be forty-four degrees fifty-one minutes, and that his declination, as found in the tables, was six degrees forty-one minutes north; then, by taking forty-four degrees fifty-one minutes from ninety degrees, the difference, which is forty-five degrees nine minutes, is the distance of the sun from the zenith; and this being added to six degrees forty-one minutes, the sun's declination, gives fifty-one degrees thirty-two minutes for the latitude required; which shews the place, in this instance, to be upon the same parallel with

with London. And if any remarkable fixed star be taken instead of the sun, the latitude may be found from its declination and altitude, in exactly the same manner.

These are the most popular methods of finding the latitude; and as what has been said upon them is sufficient to give you a general idea of the subject, I shall now proceed to the longitude, and endeavour to shew that this may be obtained, to a certain degree of exactness, in nearly as easy a manner as the former. In departing from any place, whose situation is known, we have only to find the direction we travel in, by means of the compass, and to measure the distance passed over, by an instrument proper for that purpose, and both the latitude and longitude of the place arrived at may be determined by a map or chart as follows :

Suppose a vessel departs from a place, whose latitude is fifty-seven degrees twenty minutes north, and longitude sixteen degrees east, and that it proceeds in an east south east direction seventy-five miles: then, in order to determine the situation of the place at which it is arrived, take a map or chart, as represented in fig. 11. Plate IV. in which find the place L, from whence the ship departed, and draw the right line L M, making the same angle with the meridian, east-south-east, as was shewn by the compass; and on this line set off the distance seventy-five miles from L to M, taken from the scale in
the

the figure, and M will represent, on the chart, the situation of the place required; which appears, by inspection, to be in latitude fifty-five degrees twenty-five minutes north, and longitude twenty-four degrees four minutes east.

In this example, it is supposed that the vessel preserves a uniform course through the whole of her voyage: but the same method will hold when she varies that direction; for if a like operation be performed at every change, and her situation be constantly found in the chart as before, her course or direction may be traced, by these means, from one place to another, till she arrives at the place proposed. This method, which is commonly used by mariners for determining the place of a ship at sea, would be the most eligible of any yet known, on account of the ease with which it may be practised, were it not liable to so many obvious objections: few charts are properly constructed; considerable errors will arise in estimating the course and distance; and by tempests and unknown currents in the ocean, such irregularities may be occasioned, as will render it utterly impossible to ascertain the situation of the vessel with any degree of precision; and, consequently, before an estimation of this kind can be depended upon, it must be corrected from time to time by astronomical observations.

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LETTER IX.

THE SAME SUBJECT CONTINUED.

ANOTHER method for finding the longitude of places, is by means of a chronometer, or an instrument for measuring time. This excellent machine, so useful in the common affairs of life, is capable of affording us information upon subjects that seem to have little or no connection with it; but genius and industry find analogies where vulgar apprehension is blind. If a watch or clock could be so constructed as to measure time with accuracy and precision, at all seasons, and in all places, such an instrument might be used to discover the longitude of places with the greatest ease and facility.

To illustrate this subject, we must consider the manner in which time is estimated. When the sun, in his apparent daily course round the earth, comes over any particular meridian, it is then twelve o'clock, or noon, at all places that lie under that meridian; but at all other places, it is either before noon, or after noon, according to their situation. The sun, moving from east
to

to west, must pass over the meridian N B S before he comes to the meridian N A S; and consequently, when it is noon to the inhabitants who live under the meridian N B S, it will be some time before noon to the inhabitants who live under the meridian N A S. And, on the contrary, when it is noon at those places which are situated under the meridian N A S, it will be some time after noon to the places which are situated under the meridian N B S.

Pl. IV.
fig. 12.

But as the sun appears to move uniformly round the earth, and to describe a circle that contains 360 degrees in twenty-four hours, he will of course move through an arc of fifteen degrees in an hour. When it is noon, therefore, at London, and at all other places that lie under the same meridian, it will be one o'clock in the afternoon at all those places that lie under the meridian fifteen degrees to the east of that of London; and eleven o'clock in the morning, at all those places that lie under the meridian fifteen degrees to the west of that of London. If the distance of the meridians be thirty degrees, it will make two hours difference in the time; and if forty-five degrees, three hours; and so on, reckoning according to the situation of the places,

To

To make this matter still plainer, let us consider the situation of any two particular places ; for instance, that of London and Paris. The meridian of Paris is two degrees twenty-five minutes east of the meridian of London ; and this difference, reckoning after the rate of fifteen degrees to an hour, is nine minutes and four seconds of time. When it is at noon at London, therefore, it will be nine minutes and four seconds after noon at Paris ; and on the contrary, when it is twelve o'clock at Paris, it will be only fifty minutes and fifty-six seconds after eleven at London : so that the clocks at London, ought to be slower than those at Paris by nine minutes and four seconds. In like manner, the meridian of New York, in North America, being seventy-four degrees four minutes west of that of London, the difference of time at those places will be four hours, fifty-six minutes, and sixteen seconds ; so that when it is noon at London, it is only three minutes and forty-four seconds after seven o'clock in the morning at New York.

From these circumstances you will readily observe, that as places differ in longitude, or are situated under different meridians, so the clocks and watches of those places, supposing them to be well regulated, will shew different hours at the same moment of absolute time ; a difference of fifteen degrees in longitude, always producing a difference of one hour in the time shewn by
of

those instruments. Knowing, therefore, the difference of time between two clocks, or watches, well regulated, at different places, it will be easy to find the difference of longitude of those places, by reckoning after the rate of fifteen degrees for every hour, and a quarter of a degree for every minute.

The difference of time shewn by the clocks and watches of different places, will not appear to you in the least surprising, when you consider, that whilst it is noon with us, there are countries towards the east, where the sun is just setting; and others towards the west, where he is just rising; so that it is evening with the one, and morning with the other, at the same instant that it is mid-day with us. With our antipodes, or those who live directly opposite to us upon the globe, the difference is still greater: it is noon with us, when it is midnight with them, and noon with them when it is midnight with us; their time, as well as their situation, being always directly opposite to ours. These considerations will clear the subject from all ambiguity, and you will now be able to perceive in what way a clock or watch may be used to discover the longitude.

Suppose I had a watch of such excellent workmanship, that, being once regulated for that purpose, it would always show me, in whatever part of the world I might be, the exact time it was then at London; by means of such a watch,

I should be presently enabled to tell the longitude of the place I am in. For this purpose, I have nothing more to do than to find when the sun comes to the meridian of the place, or, which is the same thing, when he is exactly south: at this moment it is twelve o'clock; and by comparing the time thus found with the time shewn by my watch, the difference, turned into degrees and minutes, will shew the longitude of the place required.

To illustrate this by an example; suppose I was at Petersburg in Russia, and wanted to find the longitude of that city from London. Not chusing to trust to the common account of time, as it is shewn by the clocks and watches at Petersburg, I find when the sun comes to the meridian, and know it to be then exactly twelve o'clock. At this moment I look at my watch, and find that, instead of its being twelve o'clock by that, it is only nine hours, fifty-eight minutes, forty-four seconds. From this I conclude that, when it is noon at Petersburg, it is before noon at London, and that the difference is two hours, one minute, and sixteen seconds; which, by allowing fifteen degrees to an hour, answers to thirty degrees nineteen minutes. Since, therefore, the longitude of every place is reckoned from London, and the noon at Petersburg arrives sooner than the noon at London, I know
the

the longitude of that city to be thirty degrees nineteen minutes east of London.

Instead of being in a place whose situation is known, suppose I was upon the ocean, near the coast of some country, whose name I wanted to discover. I determine the moment when it is noon, in the same manner as before, and looking at my watch, I find it to be five hours six minutes, twenty-eight seconds, in the afternoon at London; from whence I conclude, by allowing fifteen degrees to an hour, that I am in a place whose longitude is seventy-six degrees thirty-seven minutes west of London. By this means I know precisely the meridian I am under; but I am yet uncertain in what particular part of that meridian I am. To discover this, I find, by observing the height of the sun at noon, that the latitude of the place is thirty-seven degrees forty minutes north of the equator; and by looking into a map or chart, I find that the place having this latitude and longitude is Port Royal in Jamaica, which is therefore the place at which I am arrived.

In this easy manner the longitude of all other places might be discovered, provided the time-keeper, or watch, be subject to no irregularities, but always shews the time exactly as it would be found at London, at the instant of observation. This kind of accuracy, however, cannot be expected. Every mechanical instrument, to what
degree

degree of perfection soever it may be brought, must be subject to injuries from various causes. The irregular motions of a ship at sea, must, in particular, affect it considerably, and this is a source of error to which no adequate remedy can be applied.

It must be observed, however, that a great deal more has been done upon this subject than could have been expected. That excellent artist, Mr. John Harrison, considered it with an indefatigable and unwearied attention; and his inventions for removing the imperfections to which clock-work is liable, appeared to the commissioners of longitude so deserving of encouragement, that they allowed him several considerable gratuities, to enable him to bring his ideas to perfection. From a trial of his watch, made in the years 1761 and 1762, in a voyage to Jamaica, it was found to have erred one minute, fifty-four seconds and an half in about five months; and in another voyage to Barbadoes, the mean daily error was about two seconds and an half, which, though it did not fully answer the wishes of the public, the commissioners ordered him the sum of 10,000*l*. And some time afterwards, in consequence of his explaining the principles of his time-keepers, in such a manner as to enable others to make them with the same accuracy, and upon this being done to a still greater degree of perfection by Mr. Kendall, he received the remaining moiety of the parliamentary reward.

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If

If a watch, or time-keeper, like that above mentioned cannot be procured, we have another method for finding the longitude of places, afforded us by the eclipses of the moon. The moon, it is well known, shines by means of the borrowed light which she receives from the sun; and when the earth is interposed between these two bodies, the moon must, of course, be deprived of her light, and become obscure. And as this obscurity is, at that time, real, and arises from an absolute defect, or want of light in the moon; the phenomenon must be seen in the same manner upon every part of the earth, where the moon is above the horizon of the place at the time the eclipse happens. This is precisely the thing wanted: any appearance that can be observed at two distant places at the same moment of absolute time, will enable us to compare the time as it is reckoned at those places, and, by that means, to find the meridians under which they are situated.

The moment the moon begins to be obscured, by entering into the earth's shadow, is called the beginning of the eclipse; and the moment she leaves the shadow, the end. And if both these be properly observed, and the time between them be taken, this mean time is called the middle of the eclipse. The moon is sometimes entirely hid by the earth's shadow, and is then quite invisible. This is a total eclipse of the moon; and, in this case, the moment when

the moon disappears, is called the beginning of total darkness; and the moment when she begins to appear again, the end. But when only a part of the moon is obscured, the eclipse is called a partial one; and we have then only to observe the moment when it begins and ends. It is also to be observed, that these eclipses happen only about the time of the full moon, and even then not often.

From these circumstances it will readily appear, that if an eclipse of the moon be observed at any two places which lie under the same meridian, the clocks of those places, supposing them to be perfectly true, will shew either the beginning or the end of the eclipse at the same time; but if the two places lie under different meridians, the clocks of those places will show the beginning or end to be at different times. If the two meridians are fifteen degrees distant from each other, the difference of time will be one hour; if thirty degrees, two hours, and so on in proportion. An eclipse of the moon, therefore, being observed at two different places at the same absolute time, will furnish us with the means of discovering the longitude of those places. If the time-pieces of one place show the beginning of the eclipse to be at twelve o'clock, and the time-pieces of the other at one, the difference of longitude between these two places will evidently be fifteen degrees, and so of any other two places whatever.

But, by this method, as far as it has been hitherto explained, we must compare these observations with those made at a place whose longitude is known, before we can find the distance between the meridians under which they are situated. If I am in a place whose situation is unknown, and have an opportunity of making observations on an eclipse of the moon, these observations will be of no service to me, without I can compare them with those made at London, or some other place whose situation is known. To do this when I return to London, would not answer my purpose: I want to inform myself upon the spot.

This information is happily provided for me. The theory of the moon is now so well understood, that we are not only able to foretell all the eclipses that will happen, but can also calculate the beginning and end of those eclipses to the greatest degree of precision. In most of our common almanacs they may be found, according to the time they will happen at London; and in some other performances of this kind, they are computed for several years to come. To find the longitude, therefore, of any unknown place in which I may happen to be, I have only to provide myself with one of these almanacs, and by comparing the time of the beginning or end of an eclipse, with the time as it is calculated for London, I can immediately find the difference

difference between the meridian of London and that under which I am situated.

This method is, however, subject to several objections. Eclipses of the moon happen too seldom to be of any great service at sea; the mariner is almost constantly in want of information, and must therefore make use of some other means for obtaining it. Besides this, the beginning and end of an eclipse cannot be distinguished with sufficient exactness: they arrive almost insensibly, so that even with a telescope, we cannot be sure of not having committed an error of several seconds. But as the error must be nearly the same for the beginning as the end, the way to avoid it, is by taking the mean time between the two observations, and comparing it with that shewn by the almanac.

Eclipses of the sun, and occultations of the fixed stars, may likewise be employed for determining the longitude of places, but in a different manner from those of the moon, and by means of calculations that are too difficult and perplexing to admit of a familiar explanation. The reason of which is, that the sun is subject to no real deprivation of his light, but is only partially obscured, by the interposition of the moon, which being now between the sun and the earth, prevents his rays from reaching us as at other times. The moon appears to obscure the sun only to the inhabitants of some particular places, so that an eclipse of the sun

may frequently be observed at London, while at Paris there is not the least indication of such a phænomenon. On the contrary, the moon is really deprived of her light by the interposition of the earth, and consequently an appearance of this kind may be seen at all places where the moon is above the horizon at the time the eclipse happens.

From what has been said you will easily perceive, that if any other of the celestial bodies were from time to time, really deprived of their light, they might be employed to determine the longitude of places with the same success as eclipses of the moon. The satellites of Jupiter are bodies of this kind, whose eclipses afford us more frequent means of information than those of the moon: they pass so often into the shadow of that planet, that there is scarcely a night in which one or other of them is not eclipsed; and they appear and disappear so instantaneously, that, by means of a good telescope, we can determine the time of the phænomenon to within a second of the truth at least. The first, or nearest satellite to Jupiter, is the best for this purpose; for as it is quicker in its motion than either of the rest, it will of course be more frequently eclipsed.

Jupiter, as I have already informed you, has four satellites, or moons, which revolve round him in different orbits, in the same manner as the moon revolves round the earth. A
simple

simple inspection of Fig. 13. Plate IV. will give you a perfect idea of the manner in which these satellites are eclipsed. S represents the sun, J Jupiter, S S his shadow, and 1, 2, 3, 4, the satellites, according to the order in which they move. When either of the satellites enters into the shadow S S, it becomes immediately invisible; and the moment when it disappears, is called the immersion of that satellite. After being for some time totally hid from our sight, it again instantly appears on the contrary side of the shadow; and the moment when it becomes visible, is called the emergence of the satellite.

The immersions and emergences are both equally proper for determining the longitude; for as the appearances are the same at all places where Jupiter is at a sufficient height above the horizon, the difference of time shewn by the clocks and watches of those places, at the moment when either of the appearances are observed, will shew the meridians under which the places are situated. We have tables, ready calculated, to shew the time when these eclipses will happen, for the meridian of Greenwich, to the greatest precision. Suppose now, an observer, who is provided with these tables, a good telescope and a well regulated clock, has an opportunity of observing either the beginning or end of an eclipse of one of Jupiter's moons, upon any part of the earth,

where he may happen to be; he has only to note the precise moment when the satellite immerses into, or emerges out of Jupiter's shadow, and this time, compared with the time which is shewn by the tables for Greenwich, will give the longitude required.

These eclipses are very convenient for finding the longitude at land, because they happen almost every day when Jupiter is visible; but unfortunately they are but of little use at sea, where a knowledge of this kind is most wanted; the rolling of the ship rendering it impossible to make nice telescopical observations with any degree of accuracy. If we could see the satellites of Jupiter with the naked eye, as well as we can the moon, the method would be attended with no difficulty; it might be practised by any common sailor on board, and the longitude would then be found with nearly as much ease and certainty as the latitude. We have several methods for finding the true time at any place by celestial observations; and if a good pocket watch be previously regulated by these means, the difference between the time when the phenomenon happens, as shewn by the watch, and the time as shewn by the tables, being converted into degrees, by allowing 15 to an hour, will give the longitude of the place from London.

Several

Several attempts have been made to adapt telescopes to the purposes of marine observations, but they have all hitherto failed of success; and there is reason to fear, that the obstacles which stand in the way of this improvement are such as cannot be removed. One of the methods which have been thought of for rendering the use of the telescope easy on board a ship, is by fixing a chair, in such a manner that it shall not be agitated by the motions of the vessel. If a chair could be so balanced, it would then be as easy to observe an eclipse at sea as at land; but this has not yet been properly effected. The late ingenious Mr. Irwin, contrived a machine of this kind, and laid claim to the parliamentary reward, offered for the discovery of the longitude; but as it was judged to be defective, his hopes were disappointed, and his invention of course neglected.

Such are the difficulties with which this important subject is so perplexed and embarrassed, that all the resources of art and genius have hitherto been ineffectual to remove them. By applying to the heavens, however, we have another method afforded us, which, although it be attended with some imperfections, is that in which astronomers at present have the greatest confidence, and hopes of success. This method is likewise derived from observations
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on the moon, not when she is eclipsed, but at any time whatever, when she is visible above the horizon of the place where the observations are to be made. Eclipses of the moon happen too seldom to be of any great service at sea, and the planet Jupiter is, for a great part of the year, invisible; but the moon is almost continually offering herself to our view. This method, therefore, notwithstanding the long calculations with which it is attended, seems to be the best adapted to general use of any that has yet been discovered.

The moon rises about three quarters of an hour later every day than the preceding one; and as she changes her place considerably, from day to day, amongst the stars, these changes become proper for determining the longitude. If the moon be observed to day to be near any fixed star, she will appear to-morrow, at the same hour, to be considerably distant from it, towards the east; and this distance is sometimes more than fifteen degrees: which being so considerable, her motion will serve to mark any small portions of correspondent time with sufficient exactness. Now if the distance of the moon from any fixed star, together with the exact time, be observed at sea, and the time when it has the same distance be computed for the meridian of Greenwich, the difference between the computed time and the observed time, will give the difference of longitude, in the
same

same manner as if the time had been found by means of an eclipse of the moon, or one of Jupiter's satellites.

In the Nautical Almanac, a work printed under the authority of the commissioners of longitude, for the purpose of facilitating astronomical computations, the distances of the moon from the sun, and from certain fixed stars, are ready computed for every day at noon, and every three hours afterwards, for the meridian of Greenwich; with a rule for finding the time, answering to any given distance whatever. Suppose now, that I am at sea, and want to find the longitude of the place I am in: I chuse some remarkable fixed star, whose name and situation is known, and find with a quadrant the angular distance between that star and the moon; and by a watch, previously regulated for that purpose, the exact time when the observation was made. This being done, I look into the almanac, and find what time it is at Greenwich when the moon and star have the same distance; and this time being compared with the time of observation, will, by allowing 15 degrees to an hour, give the longitude of the place required.

The names and places of the brightest fixed stars, are to be found in the "Tables requisite to be used with the Nautical Almanac," together with the methods made use of for obtaining their true distances from the moon at the time of observation. For it is to be noted, that the
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distance

distance found by the quadrant, is not that which is to be used in determining the longitude, but the distance as it would appear to a spectator placed at the earth's center. This is the distance as it is computed for Greenwich; and in order that they may agree, it must be determined in the same manner for the place of observation. The necessity of these operations, will be sufficiently obvious from the consideration of the earth's being a globe; but the calculations upon which they depend, are too perplexed and laborious to admit of a familiar explanation. They are deduced from the principles of spherical trigonometry, and can only be practised by those who have a knowledge of that subject.

This last method of finding the longitude, which is founded upon observations of the moon, is, by the general consent of astronomers, the best that has yet been discovered. It is perplexed with tedious and difficult calculations, that render it improper for general use; but to a person of skill and abilities, the time and labour it requires are the principal objections against it. The success of any method, depends upon the accuracy with which it can be practised; and as this is the case, it may not be amiss to give you some idea of the degree of precision that we may hope to obtain in finding the longitude from lunar observations; or, which is the same thing, by taking the distance between the sun and moon,

moon, or between the moon and some noted fixed star.

The motion of the moon in her orbit, being much greater than that of any other of the celestial bodies, occasions such a considerable change of her place, as is better adapted to discover small differences of time, than can be obtained by observing any other body whose motion is slower. If the motion of the moon was more rapid than it is, it would afford us the means of attaining a still greater degree of perfection; and, on the contrary, if her motion was slower, so that we could scarcely discern her change of place from one day to another, we could receive no advantage from it in discovering the longitude. The moon's daily motion in her orbit being about thirteen degrees, her hourly mean motion is about half a degree, or one minute of a degree in two minutes of time; so that if an error of one minute be committed in calculating the place of the moon, it will produce an error of two minutes in time, or half a degree of longitude.

It was not till within half a century past, that astronomers were able to calculate the place of the moon to within less than six or seven minutes of the truth; and this error was so considerable, that no use could be made of lunar observations in discovering the longitude, either at sea or land. Sir Isaac Newton was the first who discovered the true cause of the inequalities

ties in the moon's motion, which before his time were considered as inexplicable; and the late Professor Mayer of Gottingen, following the theory of Newton, has formed a set of lunar tables, so accurate and perfect, that the place of the moon may be determined in any part of her orbit, to within a minute of the truth at least.

But, besides the error here noted, several others will be apt to arise from the instrument and the observations. The most experienced observer cannot be sure that he has not committed an error of one or two minutes, and this joined to the former one, will produce in the whole a mistake of three minutes in time, which is equivalent to one degree and a half of longitude. To avoid this, it is proper that a set of observations should be made by several persons at the same time; and as it is most likely that they will be all defective, some making the result too great, and some too little, therefore by a mean taken between them, the longitude may probably be found to within a degree of the truth; which, in most cases, is sufficiently accurate, provided we could always be sure of having attained it.

LET.

LETTER X.

OF THE DIFFERENT LENGTHS OF DAYS AND NIGHTS,
AND THE VICISSITUDES OF THE SEASONS.

NATURE is always grand in her designs, but frugal in the execution of them: sublimity and simplicity are the striking characteristics of her workmanship. From a few simple principles she produces the most astonishing effects, and charms us no less by the infinite diversity of her operations, than by the skill and contrivance which are manifested in the performance of them. The sun, moon, planets and stars, are all governed by the same invariable laws; the single principle of gravitation pervades the whole universe, and puts every spring and wheel of it in motion. From the indiscernible atom, to the vast and immeasurable luminaries of heaven, every thing is subject to its dominating influence; and from this active, invisible, and invigorating agent, proceeds all that order, harmony, beauty, and variety, which so eminently distinguishes the works of creation.

But of all the effects resulting from this admirable scene of things, nothing can be more
pleasing

pleasing and agreeable to a philosophic mind, than the alternate succession of day and night, and the regular return of the seasons.

“ Sweet is the breath of morn,
 “ And sweet the coming on of grateful evening mild.”

When the sun first appears in the horizon, all nature is animated by his presence; the magnificent theatre of the universe opens gradually to our view, and every object around us excites ideas of pleasure, admiration and wonder. After “riding in all his brightness” through the vault of heaven, he is again hid from our sight, and we are now presented with a new spectacle of equal grandeur and sublimity. The heavens are on a sudden covered with innumerable stars; “the moon rising in clouded majesty, unveils her peerless light;” whilst the silent solemnity of the scene, fills the mind with sentiments and ideas beyond the power of language to express.

Variety is the source of every pleasure; and the bountiful Author of nature, in the magnificent display of his wisdom and power, has afforded us every possible means of entertainment and instruction. What a pleasing succession of scenes results from the gradual vicissitudes of the seasons? Summer, winter, spring and autumn, lead us insensibly through the varied circle of the year; and are no less pleasing to the mind,
 than

than necessary towards bringing to maturity the various productions of the earth. Whether the sun flames in the solstice, or pours his mild effulgence from the equator, we equally rejoice in his presence, and bless that omniscient Being who gave him his appointed course, and prescribed the boundaries which he can never pass.

These phænomena depend upon the most simple and evident principles; and as you will naturally be desirous of knowing in what way they are effected, I shall omit all further digressions, and proceed immediately to the illustration of the subject. In the first place, then, it is to be observed, that the alternate succession of day and night is occasioned merely by the uniform rotation of the earth upon its axis. The earth turns regularly round upon this line, once in every twenty-four hours; and as only one half of the globe can be illuminated at the same time, it is evident that any particular place upon the earth will sometimes be turned towards the sun, and sometimes from it; and being constantly subject to these various positions, will enjoy a regular return of light and darkness; as long as the place continues in the enlightened hemisphere it will be day, and when, by the diurnal rotation of the earth, it is carried into the dark hemisphere it will be night.

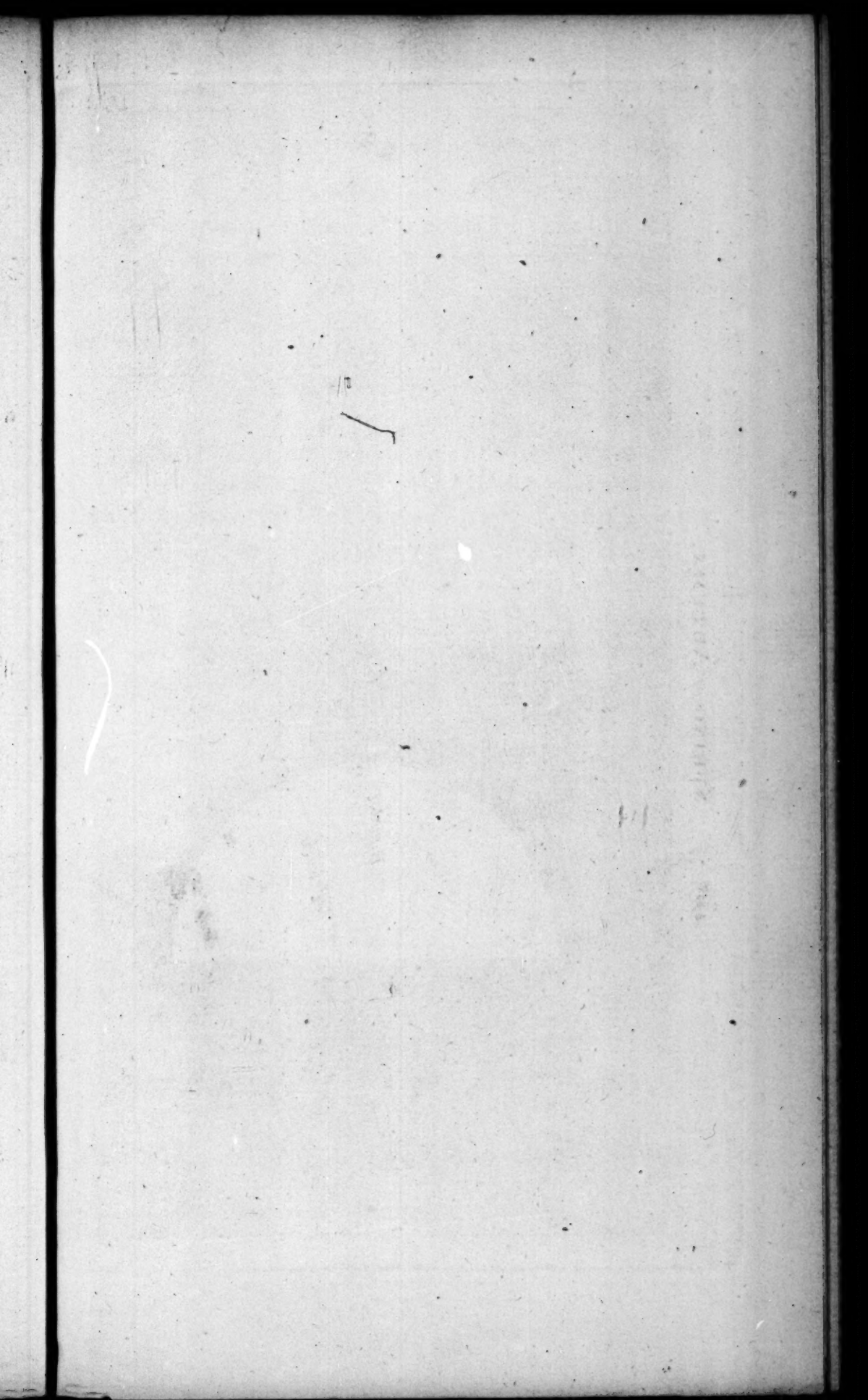
The motion of the earth upon its axis, is from west to east; and this occasions an appa-

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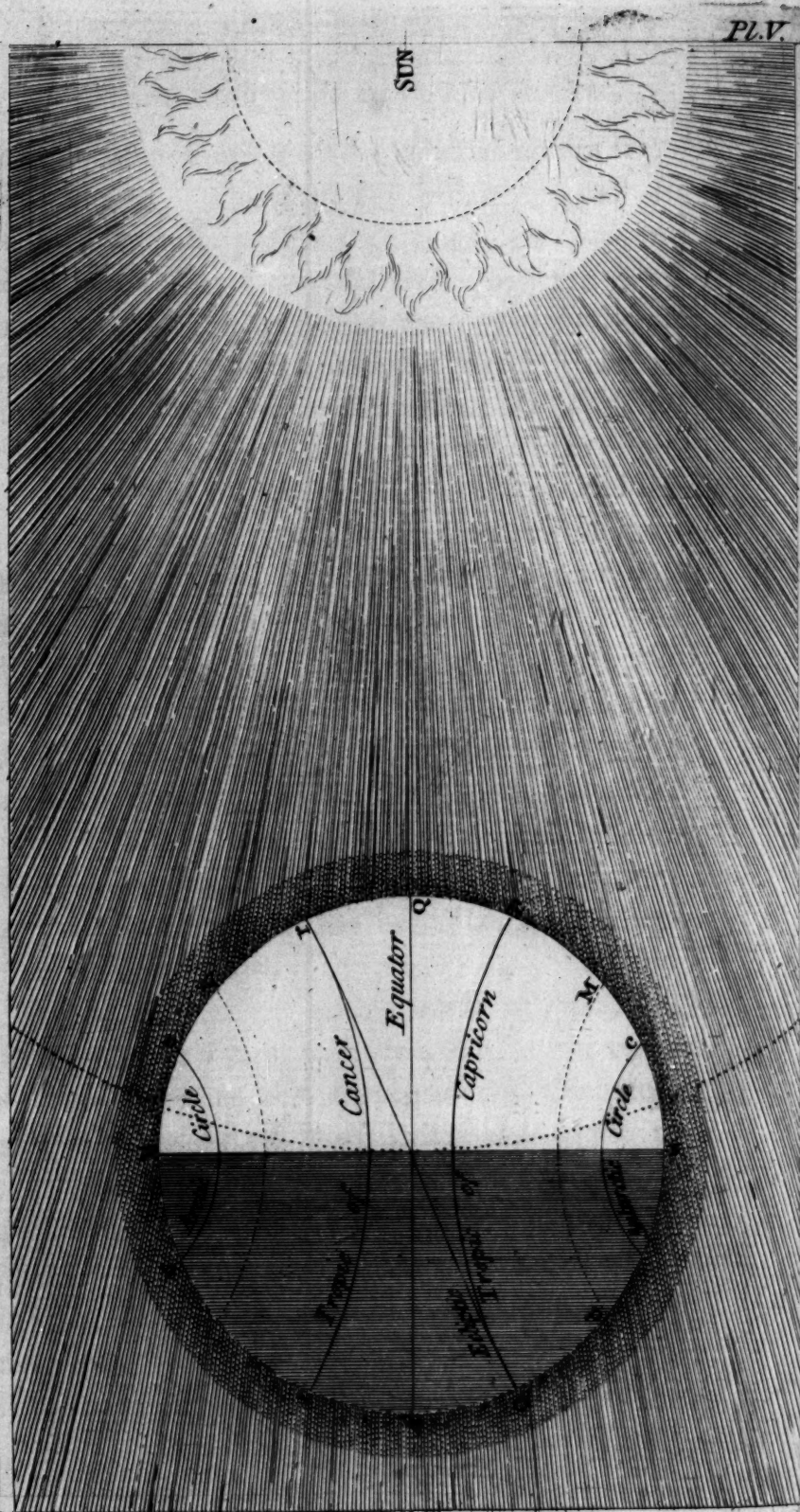
rent

rent contrary motion of the celestial bodies from east to west. The sun, for instance, seems to make his daily progress through the heavens from the east towards the west; but this is an optical fallacy, arising from the opposite motion of the earth. For a spectator being placed in any part of the dark hemisphere, will, by the rotation of the earth upon its axis, be brought gradually into the enlightened one; and as the sun first appears to him in the east, that luminary will, it is evident, seem to ascend higher and higher towards the west, in proportion as the spectator moves in a contrary direction towards the east: so that whether the earth turns round upon its axis once in twenty-four hours, or whether the sun, together with all the other celestial bodies, move round the earth in that time, the appearances will be exactly the same; but the latter notion has been shewn to be unphilosophical and absurd.

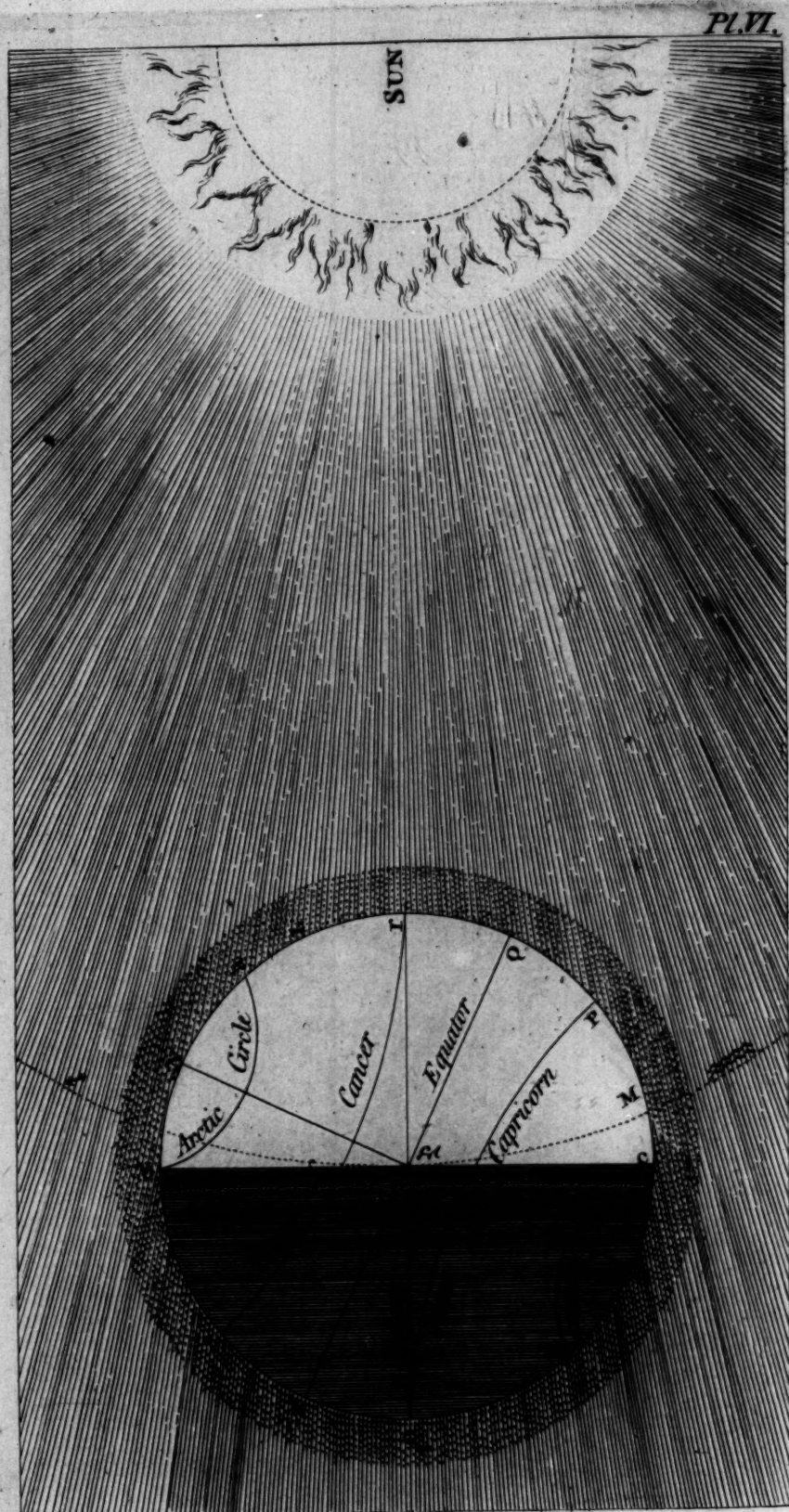
Every planet, on which observations have been made, is found to have a revolution upon its axis; and as this revolution is the cause of a constant succession of day and night to every part of their surfaces, so an inclination of the axis of any planet to the plane of its orbit, occasions the vicissitudes of the seasons. Jupiter, whose axis is nearly perpendicular to the plane of his orbit, has equal days and nights continually on every part of his surface: their
length



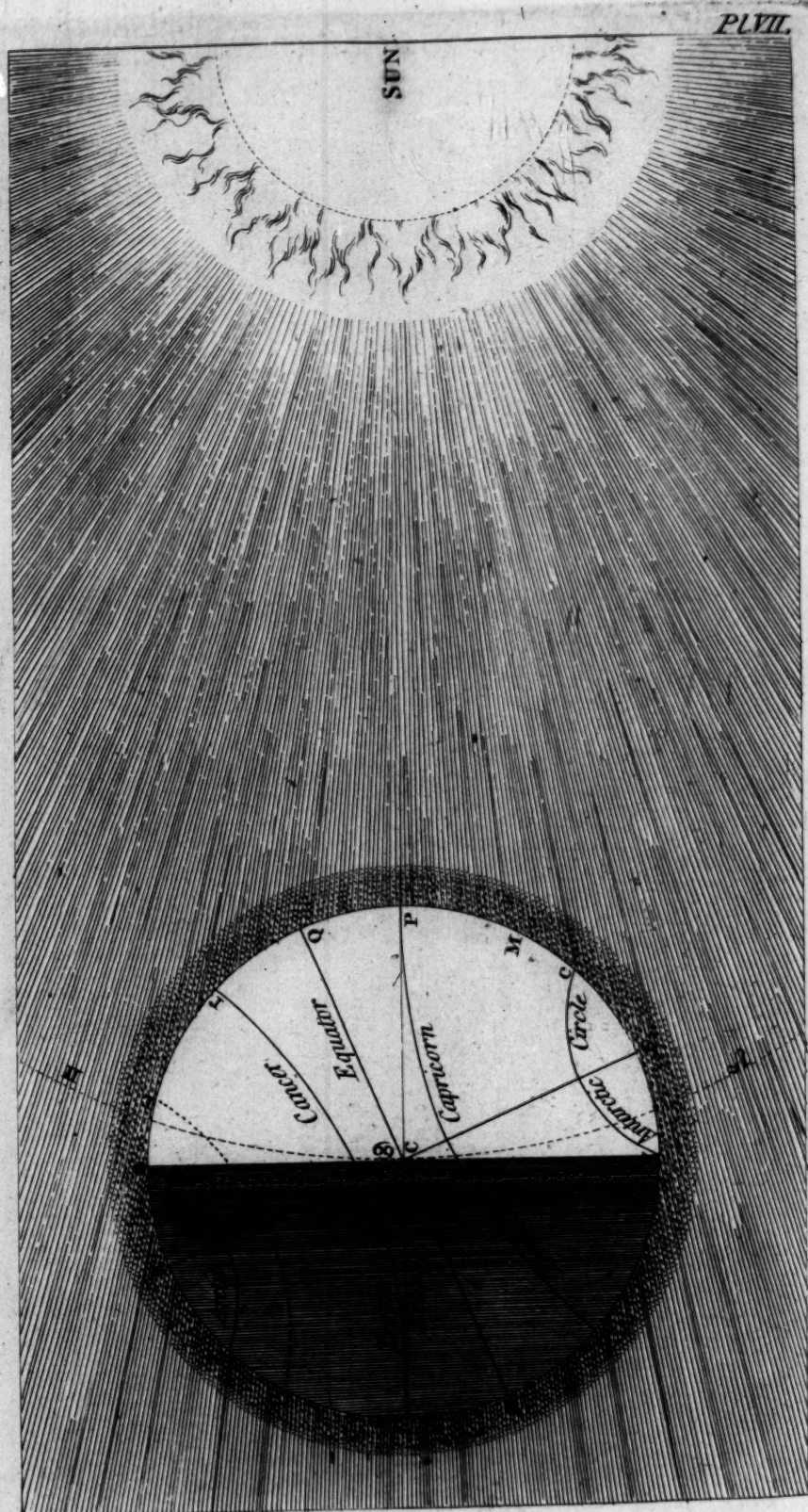
SPRING or AUTUMN.



THE SUMMER SEASON.



THE WINTER SEASON.



length being each four hours and twenty-eight minutes. But Venus, the Earth, and also Mars, according to the late discoveries of Mr. Herschel, having their axes inclined to the planes of their orbits in an angle considerably less than that of 90 degrees, are subject to an annual change of their seasons, and a great variety in the length of their days and nights.

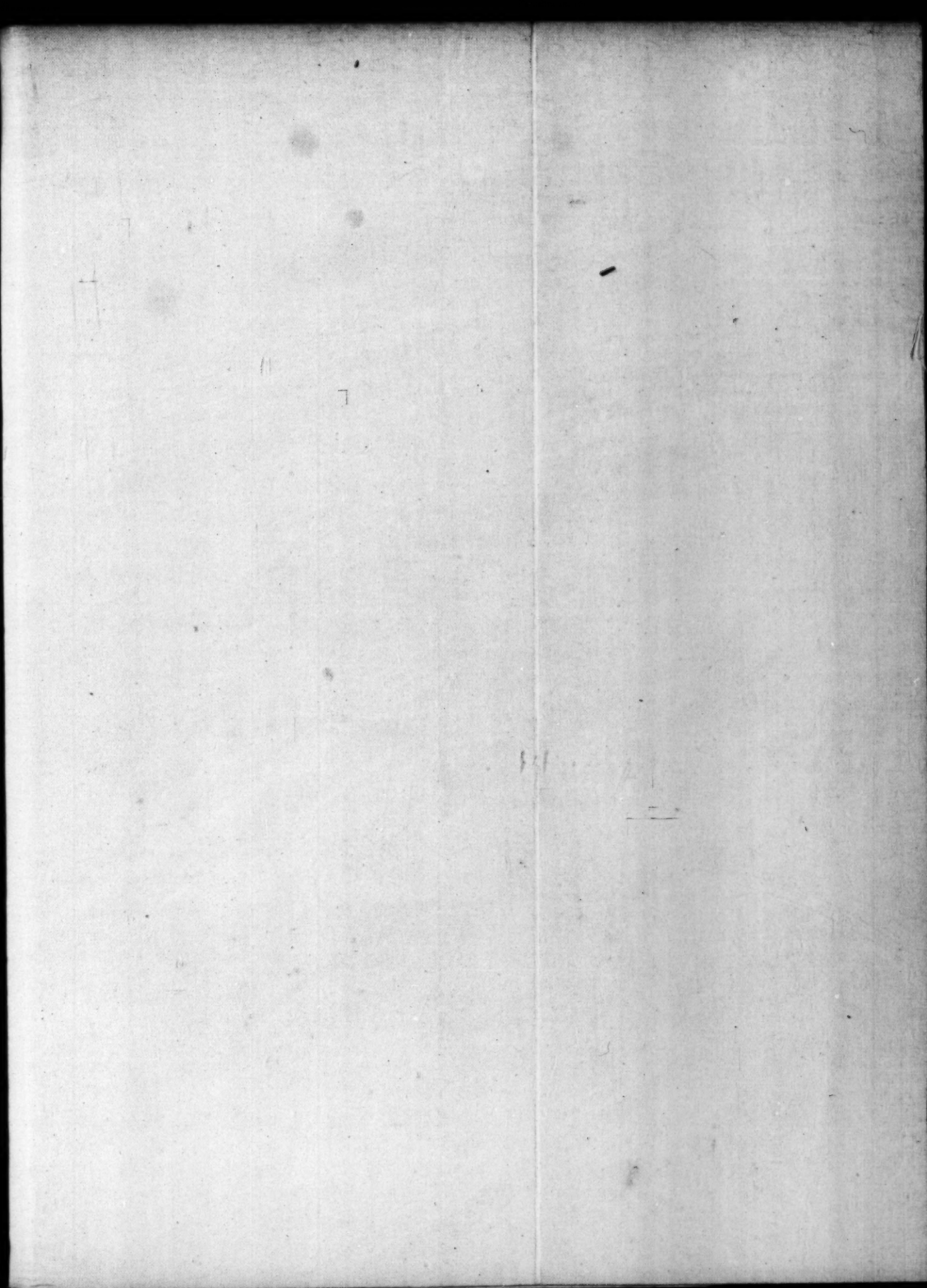
The circle which is the boundary of light and darkness is called the terminator; and it is evident, from a bare inspection of fig. 1. Pl. V. that if the axis of the earth be perpendicular to the plane of its orbit, the terminator will pass through the two poles, and divide each of the parallels of latitude *tr*, *OP*, &c. into two equal parts. And as the uniform rotation of the earth upon its axis occasions every place to describe equal parts of its parallel in equal times, the days and nights will, of course, be equal all over the globe, except at the poles, where the sun will neither rise nor set, but remain continually in the horizon.

But, on the contrary, if the axis of the earth be inclined to the plane of its orbit, as in fig. 2. Pl. VI. all the parallels except the equator, will be divided by the terminator, into two unequal parts, having a greater or less portion of their circumferences in the enlightened, than in the dark hemisphere, according as their situation is

towards the north or south poles of the world.

Pl. VI. All those places which lie under the northern parallels, will have their days longer than their nights; and on the contrary, those places which lie under the southern parallels will have their nights longer than their days; whilst at the equator, the days and nights will be continually equal to each other. And if the inclination of the axis be reversed, as in fig. 3. Pl. VII. the parallels will be still unequally divided by the terminator, but the phenomena will be directly the contrary. All those places which lie under the southern parallels, will have their days longer than their nights; and those places which lie under the northern parallels, will have their nights longer than their days; whilst the days and nights at the equator will be equal to each other, the same as before. And as the disproportion is greatest in the higher latitudes, so it is evident, that in either of these two positions of the earth, all those places that lie about the poles, will enjoy either a constant day or a constant night, as the diurnal rotation of the earth never carries them into the opposite hemispheres.

These observations being properly attended to, it will be easy to account for all the inequalities in the length of days and nights, and the change of seasons which arises from them. For
Pl. VIII, this purpose, let S represent the sun, A B C
fig. 1. D the earth's orbit; N S her axis, and the
figures



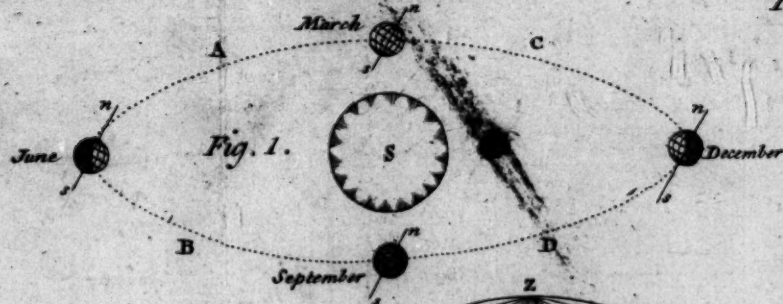


Fig. 2.

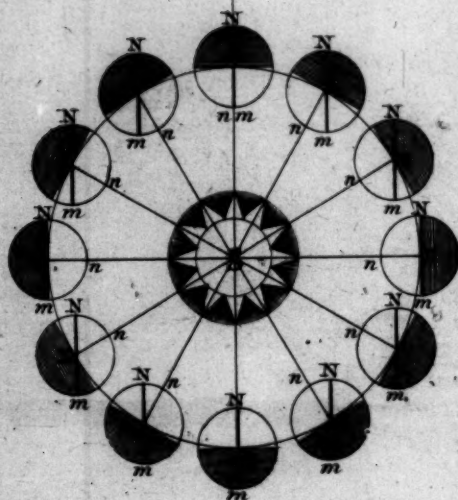


Fig. 3.

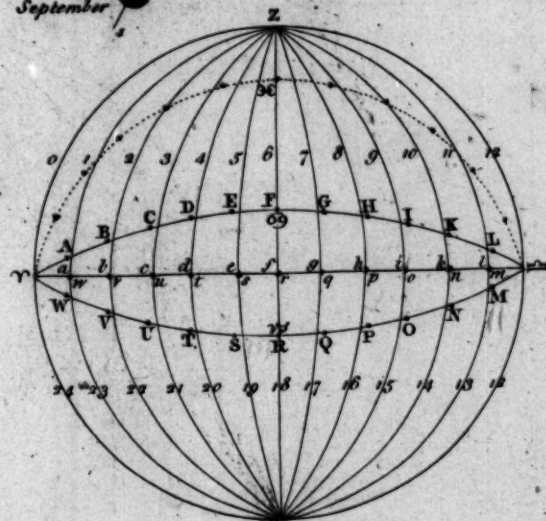
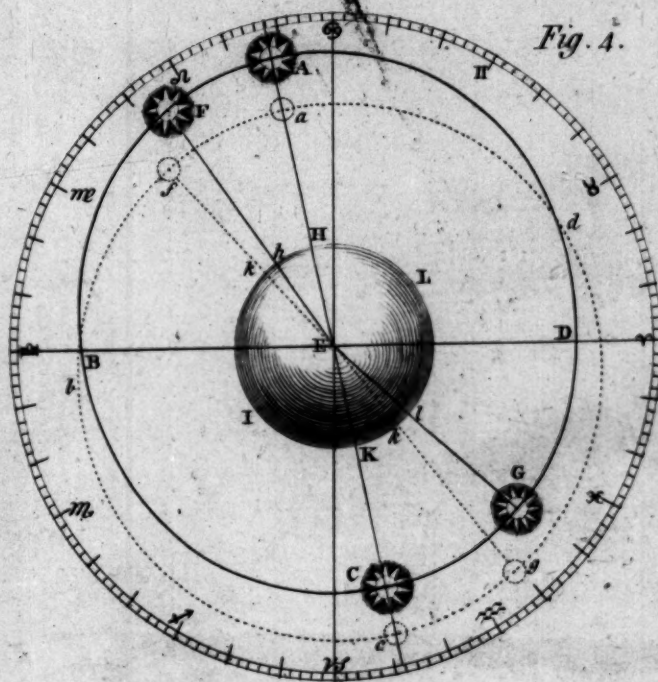


Fig. 4.



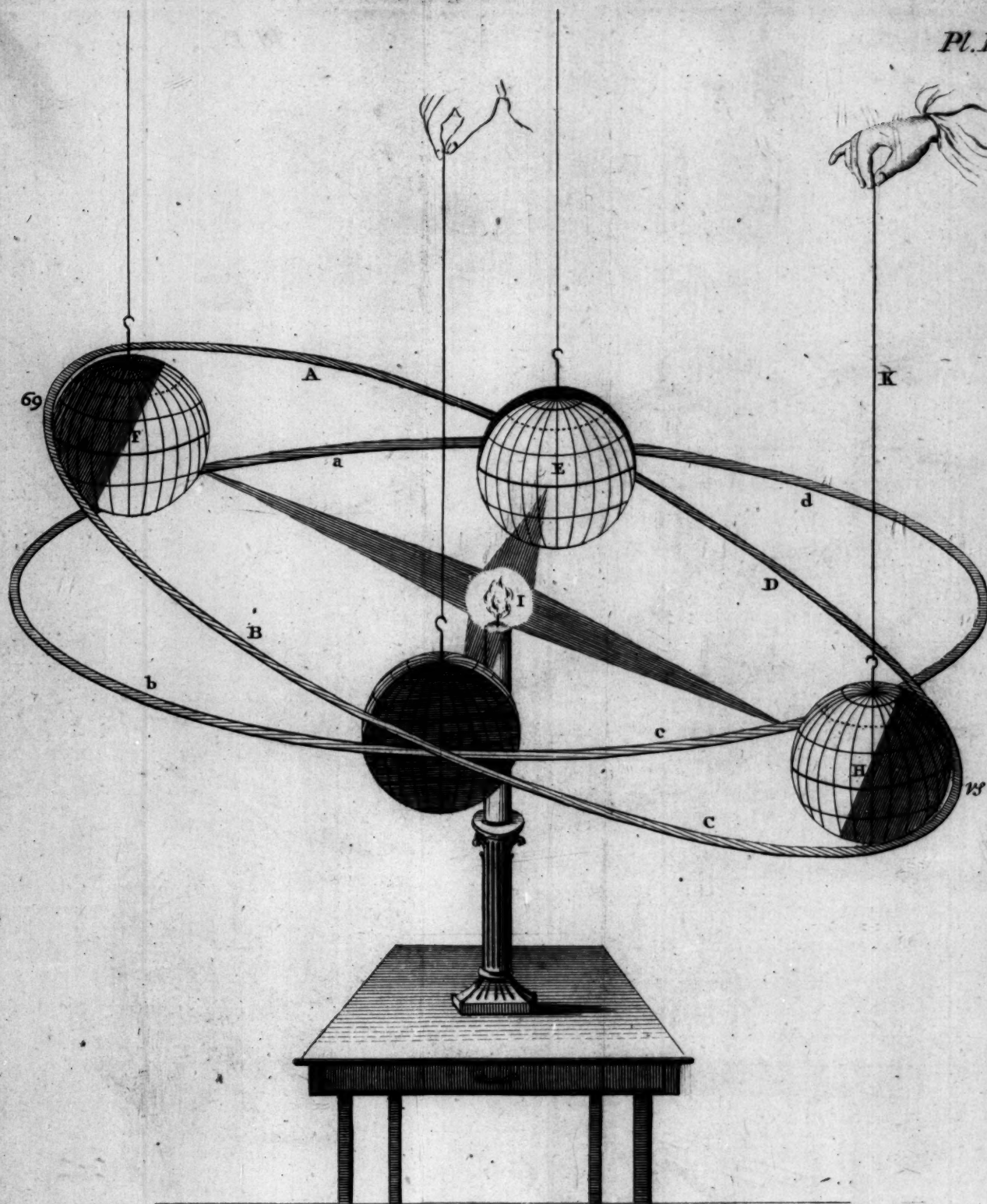
figures distinguished by the months March, June, September and December, four different positions of the earth in her annual motion round the sun. Then, since it is known from observation, that the axis of the earth is always directed to nearly the same fixed point in the heavens, it will constantly preserve the same position, and be always in a situation nearly parallel to itself, in whatever part of her orbit the earth may be in the course of her journey round the sun.

Suppose now, the earth to be in the situation which is represented by the month March; then, because a right line joining the centers of the sun and earth, will cut the surface of the earth in the equator, the terminator will pass through the two poles, and the days and nights will consequently be equal all over the globe. But when the earth, by its annual motion, is carried farther in its orbit towards A, the north pole N, of the axis, still continuing to observe the same parallel situation, will advance into the enlightened hemisphere, and in the month of June will be about twenty-three degrees and a half distant from the terminator, the south pole being at the same distance in the dark hemisphere. In the month of June therefore, the northern parts of the earth will enjoy long days and summer, whilst the southern parts will have short days and winter.

During the interval between the time of equal days and nights in March, which is called the Vernal Equinox, and the time when the day is the longest in June, which is called the Summer Solstice, the north pole will have described a quarter of a circle in the enlightened hemisphere, and will then be at its greatest distance from the boundary of light and darkness. And whilst the earth moves forward in its orbit towards B, the days will gradually shorten, till it arrives at the position denoted by the month September, when the north pole having described the other quarter of the circle, the terminator will again pass through the two poles, and the days and nights will be equal, the same as before.

This last situation of the earth is called the Autumnal Equinox, and the season is now a medium between summer and winter. And as the earth proceeds forwards in her orbit towards D, the days will shorten till December, when the north pole will be just as far in the dark hemisphere as it was in the enlightened one in June, at which time it is called the winter solstice. From the winter solstice, to the vernal equinox, the days will gradually lengthen, as the north pole approaches the terminator; and at the instant when it has again obtained that situation, the natural year, which consists of three hundred and sixty-five days, five hours, forty-eight minutes,

Pl. IX.



minutes, and forty-five seconds, is exactly completed. By the same explication, it is easy to perceive, that the inhabitants of the southern hemisphere have the same vicissitudes with those in the northern, but in a contrary order, it being winter in one hemisphere while it is summer in the other.

But lest this explanation of the subject should not be found sufficiently intelligible, I shall give you one of the most simple experimental illustrations of it I have yet seen. It is taken from Ferguson's Astronomy; but as his account is rather embarrassed, I shall make such alterations in it, as appear necessary and proper.

Take about seven feet of strong wire, and bend it into the circular form $a b c d$, which Pl. IX. being viewed obliquely will appear elliptical, as in the figure. Place a lighted candle on a table, and having fixed the end of a silk thread K, to a small terrestrial globe H, of about three inches in diameter; cause another person to hold the wire circle $a b c d$, so that it may be parallel to the table, and of the same height with the flame of the candle I, which should be nearly in the center of the table.

Having twisted the thread towards the left hand, so that by its untwisting it may turn the globe eastward, or contrary to the way that the hands of a watch move, suspend the

globe by the thread, within this circle, almost contiguous to it; and as the thread untwists, the globe, which is enlightened half round by the candle, as the earth is by the sun, will turn round its axis, and the different places upon its surface, will be carried through the light and dark hemispheres, and have the appearance of a regular succession of days and nights, in the same manner as would take place upon the earth, by means of such a motion.

As the globe turns by the untwisting of the string, move your hand slowly round the candle, according to the order of the letters *a b c d*, keeping its center continually even with the wire circle, and you will perceive that the candle, being still perpendicular to the equator, will enlighten the globe from pole to pole, through the whole of its motion round the circle; and that every place on the globe goes equally through the light and dark hemispheres, as it turns round by the untwisting of the string, and has, therefore, a perpetual equinox, or an equal portion of day and night.

The globe turning round in this manner, represents the rotation of the earth upon its axis; and the motion of the globe round the candle represents the earth's annual motion round the sun; and shows, that if the axis of the earth had no inclination to the plane of its orbit, all the days and nights in the year would be
equally

equally long, and that there would be no variety of the seasons. This is exactly what would take place, if the earth moved in the equator instead of the ecliptic; but as that is not the case, we shall now see what effects will follow from its true motion in the circle last mentioned.

Desire the person who manages the wire to hold it obliquely, in the position A B C D, raising the side ∞ just as much as he depresses the side ν , that the flame may be still in the plane of the circle; and twisting the thread as before, that the globe may turn round its axis the same way as you carry it round the candle, that is, from west to east, let the globe down into the lowermost part of the wire circle at ν , and if the circle be properly inclined, the candle will shine perpendicularly on the tropic of Cancer, and the frigid zone, lying within the arctic, or north polar circle, will be all in the light, as in the figure, and will always continue to be so, though the globe turn round its axis ever so often.

In this position of the globe, it is also evident, that all the places which lie between the equator and the north polar circle, have longer days and shorter nights; and that all those places which lie between the equator and the south polar circle have just the reverse. The sun does not set to any part of the north frigid zone, as is shewn by the candle's continually shining on it, so
that

that the motion of the globe can carry no part of that zone into the dark ; and, at the same time, the south frigid zone is involved in darkness, and the revolution of the globe can bring no part of it into the light.

If the earth were to continue in the same part of its orbit, the sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south frigid zone. At the equator it would always be equal day and night ; and at places more distant from the equator, towards the arctic circle, they would have longer days and shorter nights, whilst those on the south side of the equator would have their nights longer than their days ; so that in this case, there would be continual summer on the north side of the equator, and continual winter on the south side of it.

But as the globe turns round its axis, move your hand slowly forwards, so as to carry it from H towards E, and the boundary of light and darkness will then approach towards the north pole, and recede from the south pole ; the northern places will go through less and less of the light, and the southern places through more and more of it ; which shews how the northern days decrease in length, and the southern days increase, whilst the globe proceeds from H to E.

When

When the globe is at E, it is at a mean situation between the lowest and highest parts of its orbit; the candle is directly over the equator; the boundary of light and darkness just reaches to both the poles; and all places on the globe go equally through the light and dark hemispheres; which shews that the days and nights are then equal on every part of the earth, the poles only excepted; and there, it is evident, the sun is setting to the north pole, whilst he is rising to the south pole.

Continue moving the globe forward, and as it goes through the quarter A, the north pole will recede farther into the dark hemisphere, and the south pole advance more into the light, as the globe comes nearer to ∞ ; and when the center of it is at F, the candle will be directly over the tropic of Capricorn; the days are then at the shortest, and nights at the longest in every part of that hemisphere, from the equator to the arctic circle; and the reverse in the southern hemisphere, from the equator to the antarctic circle; within which circles, it is dark to the north frigid zone, and light to the south.

Continue both motions as before, and as the globe moves through the quarter B, the north pole advances towards the light, and the south pole recedes towards the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the globe comes to G, the
candle

candle will be again over the equator, as it was at E, and the days and nights will be equal the same as before; so that the north pole will be just coming into the light, and the south pole going out of it.

From this experiment, we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is sometimes no day nor night for many revolutions of the earth, within the polar circles; why there is but one day and one night in the whole year at either of the poles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the terminator, or the circle which is the boundary of light and darkness.—All this beautiful variety is occasioned by the inclination of the earth's axis to the plane of its orbit.

“ Some say he bid his angels turn askance
The poles of earth twice ten degrees and more
From the sun's axle: they, with labour push'd
Oblique the central globe.”

MILTON.

The earth's orbit being elliptical, and the sun constantly keeping in the lower focus, which is about 1,377,000 miles from the center, the earth will therefore, be 2,754,000 miles nearer to the sun, at one time of the year than at another; and as the sun appears constantly bigger;

ger, or under a larger angle in winter than in summer, this sufficiently proves that the earth is nearer to the sun in the former season than in the latter. But here this question will naturally arise; Why have not we the hottest weather when the earth is nearest to the sun? The earth is above two millions of miles nearer to the sun in December than it is in June, and yet in June it is the middle of summer, and in December the depth of winter; this seems a paradox.

In answer to this apparent contradiction, it may be observed, that the excentricity of the earth's orbit, or 1,377,000 miles, bears no greater proportion to the earth's mean distance from the sun, than 17 does to 1000, and therefore can occasion but little difference in the heat and cold of different seasons. But the principal cause of this difference is, that the sun's rays in winter fall so obliquely upon us, and have so large a portion of the atmosphere to pass through, that they come with less force, and spread over a larger space than they do in summer, or when the sun is at a greater height above the horizon. In the winter long nights, we have also a greater degree of cold than can be compensated for by the return of heat in the short days; and on both these accounts the cold will be much increased. Whereas in summer the sun's rays descend more perpendicularly upon us,
and

and therefore fall with a greater force, and in a greater quantity upon any particular place than when they come more obliquely. The sun is also much longer above the horizon than in winter, and consequently a greater degree of heat will be imparted by day, than can fly off by night, so that the heat will continue to increase.

LET-

LETTER XI.

OF THE NATURAL AND ARTIFICIAL DIVISIONS
OF TIME.

THE more we extend our views, the more we are perplexed and embarrassed. Things that once appeared the most familiar to our understandings, are now hid under an impenetrable veil, and become totally mysterious and inexplicable. Education is a new birth to man; but with all the advantages that art and nature can bestow, he is still a limited and confined being. Numberless are the questions that may be put to the most profound philosopher, which, if he be ingenuous, he must confess his entire inability to resolve. What is time, space, matter, or motion? Every one, who speaks of these things, imagines himself to be clearly understood, even by the most illiterate; and yet if you ask for an explanation of the question, no one is able to give a rational answer to it.

If nobody asks me, said St. Augustine, what time is, I know; but if any body asks me, I don't know. Another philosopher being desired to explain the nature of motion, got up
 I and

and walked. I cannot define it, says he, but I'll shew you the thing itself. Lucretius, speaking of Time, gives us the following idea of it.

Time of itself is nothing, but from thought
 Receives its rise, by labouring fancy wrought
 From things consider'd, whilst we think on some
 As present, some as past, or yet to come :
 No thought can think on time, that's still confess,
 But thinks on things in motion or at rest.

Mr. Leibnitz defines time to be "an order of succeffions, as space is an order of coexistences;" and Hobbs, who is still more refined in his notions, calls space the "phantasm of a thing existing, as existing." What sort of satisfaction or conviction, these definitions afford the mind, you will readily perceive, by consulting your own bosom. The fact is, they are wholly unintelligible, and instead of conveying any clear ideas of the subject, serve only to render our simple and common notions of it more perplexed and obscure. No knowledge can be obtained from a definition, but when the terms made use of in the explication of it, are better understood than the thing itself; and that this is not the case in the present instance, is pretty obvious. The nature of time, is, indeed, so intricate, that, to me, it appears incapable of admitting a clear and explicit definition. We must

must explain it by means of the terms space, matter and motion, and these are all equally mysterious and ambiguous.

The notion we attempt to form of Eternity, has ever been considered as one of the most perplexing and embarrassing conceptions of the human mind; but some modern speculators in metaphysical subtilties, pretend that there is nothing of which we have a more clear and determinate idea; and as for time, there is no such thing, it being, as they say, only a particular modification of eternity, and has no distinct, conceivable existence, independent of the subject of which it is an attribute or property. This is as much as to say, that finitude is more incomprehensible than infinitude; and that motion, which is the measure of time, cannot be conceived without it is first represented to the mind as being perpetual.

Dr. Young, in his melancholy rhapsody the Night Thoughts, has some curious poetical ideas upon this subject; he calls time heaven's stranger, and represents it as being born at the creation of the world.

That memorable hour of wond'rous birth,
When the dread Sire, on emanation bent,
And big with nature, rising in his might
Call'd forth creation, (for then time was born)
By godhead streaming through a thousand worlds.

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Mr. Leibnitz defines time to be "an order of successions, as space is an order of coexistences;" and Hobbs, who is still more refined in his notions, calls space the "phantasm of a thing existing, as existing." What sort of satisfaction or conviction, these definitions afford the mind, you will readily perceive, by consulting your own bosom. The fact is, they are wholly unintelligible, and instead of conveying any clear ideas of the subject, serve only to render our simple and common notions of it more perplexed and obscure. No knowledge can be obtained from a definition, but when the terms made use of in the explication of it, are better understood than the thing itself; and that this is not the case in the present instance, is pretty obvious. The nature of time, is, indeed, so intricate, that, to me, it appears incapable of admitting a clear and explicit definition. We must

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O

And

And again :

From old eternity's mysterious orb,
Was time cut off, and cast beneath the skies ;
The skies, which watch him in his new abode,
Measuring his motions by revolving spheres ;
That horologe machinery divine.
Hours, days, and months, and years, his children, play
Like numerous wings around him, as he flies :
Or rather, as unequal plumes, they shape
His ample pinions, swift as darted flame,
To gain his goal, to reach his ancient rest,
And join anew eternity his fire.

What is to be understood from this passage it is not easy to say. The book, however, contains much better things ; some of his thoughts being highly sublime and poetical : but his philosophical notions are, in general, affectedly mysterious and obscure.

I have mentioned these things, merely to shew you what insuperable difficulties we have to encounter, when we attempt to carry our speculations and enquiries beyond the narrow and confined limits of the human mind. Properties and effects are all that we are acquainted with : the nature and causes of things are entirely hid from us, and it is in vain to seek after them. The great Maclaurin, whose mind was as elegant and refined, as it was penetrating and comprehensive, does not, whilst he is treating on
this

this subject, attempt to give a strict and scientific definition of time. After making a number of judicious observations upon the certainty we have of our own existence, and the manner in which external objects act upon the mind, he expresses himself as follows.

“ From the succession of our own ideas, and from the successive variations of external objects in the course of nature, we easily acquire the ideas of duration and time, and of their measures. We conceive true or absolute time, to flow uniformly in an unchangeable course, which alone serves to measure with exactness the changes of all other things. For unless we correct the vulgar measures of time, which are gross and inaccurate, by proper equations, the conclusions are always found to be incorrect and erroneous. Time may be conceived to be divided into successive parts that may be less and less without end, though, with respect to any one particular being, there may be a least sensible time, as well as a *minimum sensible* in other magnitudes. But however various the flux of time may appear to different intellectual beings, it cannot at least be thought to depend upon the ideas of any created being whatever.”

Space and Time serve to measure each other reciprocally by motion: time is in a perpetual flux, and perishing; but a representation of it is preserved in the space described by motion.

The sun is the most conspicuous body in our system, and as his apparent journey through the heavens is very nearly regular and uniform, his motion is naturally fixed upon as one of the properest measures of time that is afforded us by nature. It is by means of his apparent diurnal and annual motions, that we obtain the two grand divisions of time, into days and years; and from thence all the different periods that are at present in use. The first division of the day was simply into four parts, morning, noon, evening and midnight; but as these measures are vague and uncertain, art has been called in to our assistance, and has furnished us with instruments, by which we are enabled to measure small intervals of time with greater precision.

In like manner, by combining the revolutions of the sun and moon we embrace the larger intervals, and from thence form an idea of those grand periods of time, which, by a continual and rapid succession, gave birth to so many great events, and have determined the rise and fall of all the kingdoms and empires of the earth.

Nature, by the constant succession of light and darkness, has regulated the times of labour and repose; and as these intervals are sufficiently obvious of themselves, I shall content myself, at present, with only pointing out to you such other divisions as arise from astronomical

mical

mical considerations, and which are principally used in that science. In all civil computations, a day is usually divided into twenty-four hours, reckoning twelve from midnight to noon, and twelve from noon to midnight again; but an astronomical day is the interval between noon and noon, or the time elapsed between two successive transits of the sun's center over the same meridian. This day is divided into twenty-four hours like the former; but instead of stopping at twelve, as in the civil account, astronomers always reckon on from one to twenty-four, without interruption; so, that for instance, what is called seven o'clock in the morning of April the tenth, by the civil reckoning, is called by astronomers April the ninth, at nineteen hours.

The sun appears to go round the earth in twenty-four hours, and the stars in twenty-three hours, fifty-six minutes and four seconds; so that the stars gain three minutes and fifty-six seconds upon the sun every day, which amounts to one diurnal revolution in a year; and therefore in three hundred and sixty-five days, as measured by the returns of the sun to the meridian, there are three hundred and sixty-six days, as measured by the returns of the stars to the meridian: the former of these, as has been observed before, are called Solar days, and the latter sidereal. This difference between the

solar and sidereal days, is occasioned by the immense distance of the fixed stars; for the earth's orbit, compared with this distance, is but as a physical point; and therefore any meridian will revolve from a fixed star to that star again, in exactly the same time as though the earth had only a diurnal motion, and was to remain for ever in the same part of its orbit.

But this is not the case with respect to the sun: the annual motion of the earth, occasions the sun to change his place continually amongst the fixed stars; and therefore the sun and any particular star, can never come to the meridian at the same time two days following. For as the earth advances almost a degree eastward in its orbit in the same time that it turns eastward round its axis, whatever star passes over the meridian any day with the sun, will pass over the same meridian the next day when the sun is three minutes and fifty-six seconds, or near a degree short of it. If the year contained exactly three hundred and sixty days, as the ecliptic does three hundred and sixty degrees, the sun's apparent place, so far as his motion is equable, would change a degree every day; and then the sidereal days would be just four minutes shorter than the solar ones.

PL. VIII.
fig. 2.

This matter may perhaps be made something plainer by means of a figure. For this purpose, let A B C D, &c. be the earth's orbit, in
which

which it goes round the sun every year, from west to east, according to the order of the letters, and turns round its axis, the same way, from the sun to the sun again in twenty-four hours. Let S, in like manner, represent the sun, and R a fixed star, at such an immense distance, that the diameter of the earth's orbit bears no sensible proportion to that distance; and in the figure Nnm , which represents the earth in different points of its orbit, let Nm , be any particular meridian, and N a given point or place upon the surface of the earth, lying under that meridian.

These things being premised, it is plain that when the earth is at A, the earth, sun and star will be all in the same right line; and consequently, as the earth turns round its axis, the point N will come to the sun and star at the same time. But when the earth has advanced through a twelfth part of its orbit from A to B, its motion round its axis will bring the point N a twelfth part of a day, or two hours sooner to the star than to the sun. For the star will come to the meridian, in the same time as though the earth had continued in its former situation at A; but the point N must revolve from N to n before it can have the sun upon its meridian. The arc Nn , therefore, being the same part of a whole circle as the arc AB, it is plain that any star which comes to the meri-

dian at noon with the sun, when the earth is at A, will come to the meridian at ten o'clock in the forenoon, when the earth is at B.

When the earth has passed from A to C, through a sixth part of its orbit, the point N will have the star upon its meridian at eight o'clock in the morning, or four hours sooner than it comes round to the sun; and, in like manner, when the earth has advanced forwards to D, through a fourth part of its orbit, the point N will have the star on its meridian at six o'clock in the morning; for as the earth has now proceeded through ninety degrees, or a fourth part of its orbit, it must likewise turn ninety degrees upon its axis, in order to carry the point N from the star to the sun; for the star will always come to the meridian when Nm is parallel to $RS A$, because DS , the radius of the earth's orbit, is but as a point in respect to the immense distance RS .

When the earth is at E, the star comes to the meridian at four o'clock in the morning; at F at two in the morning; and at G, the earth having gone just half round its orbit, the point N will come to the star R at midnight, it being then directly opposite to the sun; and, therefore, by the earth's diurnal motion, the star will come to the meridian twelve hours before the sun. In like manner, when the earth is at H, the star will come to the meridian at ten o'clock in the evening,

evening, or fourteen hours before the sun; at I, it will come to the meridian sixteen hours before the sun; at K, eighteen hours before him; at L, twenty hours; at M, twenty-two; and at A it will return to the meridian at the same time, and be exactly with the sun again.

The daily revolution of the earth, which, by observation, is known to be uniform, is always completed, when any particular meridian comes to be parallel to the situation which it had at any time of the preceding day: and it is plain, from the figure, that the same meridian will never be brought round from the sun to the sun again by one complete revolution of the earth upon its axis, but that it will require as much more than one revolution to finish a natural day as it has gone forward in its orbit in that time, which, at a mean rate, is the three hundred and sixty-fifth part of a circle; so that in three hundred and sixty-five days, the earth will have turned three hundred and sixty-six times round its axis; and, therefore, as one complete rotation of the earth upon its axis makes a sidereal day, there will be one sidereal day in a year more than there is solar days, be that number what it will, either on the earth, or on any other planet.

This regular return of the fixed stars to the meridian, affords us an easy method of determining whether our clocks and watches go true.

For,

For, if through a small hole in a window shutter, or in a thin plate of metal fixed to the window, we observe at what time any star disappears behind a chimney, or the corner of a house, at a small distance; then if the same star disappears the next night three minutes, fifty-six seconds sooner by the clock or watch, than it did the night before; and on the second night seven minutes, fifty-two seconds sooner; on the third night eleven minutes, forty-eight seconds sooner, and so on, it is a certain sign that the machine goes right; but if it does not observe this rule, it does not go true, and must be regulated accordingly; and as the disappearing of a star is instantaneous, we may depend upon this information to half a second at least.

Besides the divisions of time here mentioned, there are two others which relate to the year; and as they are frequently referred to by astronomers, it will not be improper to explain them. The two opposite points in which the ecliptic crosses the equator, are called the equinoctial points; and the two points where it touches the tropics the solstitial points; and the time elapsed between two successive passages of the sun through the same equinoctial or solstitial points, is called the tropical year; which, by observation, is found to contain three hundred and sixty-five days, five hours, forty-eight minutes, and forty-five and a half seconds.

And,

And, in like manner, as the tropical year is determined by the returning of the sun to the same point of the ecliptic, so the time elapsed between his departure from any fixed star and his returning to that star again is called the sidereal year, which contains three hundred and sixty-five days, six hours, nine minutes, and fourteen seconds and an half. The sidereal year is therefore, twenty minutes, seventeen seconds and an half longer than the solar or tropical year; and nine minutes, fourteen seconds and an half longer than the civil year, which is three hundred and sixty-five days, six hours; so that the civil year is almost a mean between the sidereal and tropical years.

LET-

LETTER XII.

OF THE EQUATION OF TIME; OR THE DIFFERENCE
BETWEEN MEAN TIME AND APPARENT.

IT is a circumstance worthy of observation, that throughout all nature, there is no one body, with which we are acquainted, whose motion is perfectly uniform and regular. The sun, in his apparent journey through the heavens, is supposed by the vulgar to furnish us with an accurate and just measure of time; but in this they are greatly mistaken. Astronomers have found that the motion of the sun is very unequal; and therefore equal time, which flows on for ever in the same manner, cannot be truly measured by the sun's motion. Mean, or equal time, is that which is shewn by a well regulated clock or watch; and in order that the apparent time, as shewn by a true sun-dial, may agree with this, it must be corrected by proper equations.

The difference between mean and apparent time depends upon two causes, the obliquity of the ecliptic with respect to the equator, and the unequal motion of the earth in an elliptical orbit. I shall first explain the effects of these causes separately considered, and then the united effects

effects resulting from their combination. But, before we proceed to these particulars, it will be proper to remind you, that whenever the motion of the sun is spoken of, it is not to be understood in a positive sense, as though he actually removed from one part of space to another, but only as an appearance occasioned by the real motion of the earth in a contrary direction. The phenomena are exactly the same; and astronomers sometimes mention one, and sometimes the other, according as they find it most convenient for their purpose.

This being premised, it may be observed, that since the earth's axis is perpendicular to the plane of the equator, any equal portions of the equator, will, by means of the earth's rotation upon its axis, pass over the meridian in equal times; and so, in like manner, would any equal portions of the ecliptic, provided it were parallel to, or coincident with the equator. But as the ecliptic is oblique to the equator, the daily motion of the earth upon its axis will carry unequal portions of it over the meridian in equal times, the difference being always proportional to the obliquity; and as some parts of the ecliptic are much more obliquely situated with respect to the equator than others, those differences will, therefore, be unequal amongst themselves.

Suppose, for example, that the sun and a star were to set out together from one of the equino-

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tial points, and to move continually through equal arcs in equal times, the star in the equator, and the sun in the ecliptic; then it is plain that the star, moving in the equator, would always return to the meridian exactly at the end of every twenty-four hours, as measured by a well regulated clock, that keeps equal time; but the sun, moving in the ecliptic, would come to the meridian, sometimes sooner than the star, and sometimes later, according to their relative situations; and they would never be found upon that circle exactly together, but on four days of the year, namely, on the 20th of March, when the sun enters Aries; on the 21st of June, when he enters Cancer; on the 23d of September, when he enters Libra; and on the 21st of December, when he enters Capricorn.

Pl. VIII.
fig. 3.

This may be still better illustrated by a figure. For this purpose, let $Z \gamma z \alpha$ be the earth; $ZF \gamma z$ its axis; $a b c d$, &c. the equator; $A B C D$, &c. the northern half of the ecliptic, from γ to α , on the side next to the eye; and $M N O P$ the southern half, on the opposite side, from α to γ . In like manner, let A, B, C, D , &c. be the boundaries of equal portions of the ecliptic, gone through in equal times by the sun; and those at a, b, c, d , &c. equal portions of the equator, described in equal times by the star; and let $Z \gamma z$ be the meridian.

Then, as the sun moves obliquely in the ecliptic, and the star directly in the equator, a

degree, or any number of degrees, between γ and F on the ecliptic, must be nearer to the meridian Z γ z , than a degree, or any corresponding number of degrees on the equator, from γ to f ; and the more so as they are the more oblique. The sun, therefore, comes to the meridian sooner every day, while he is in the quadrant γ F, than the star does in the quadrant γ f ; and as the motion of the fictitious star in the equator, answers to the motion of a well regulated clock, it is plain that the solar noon, in this case, will precede the noon by the clock.

Whilst the sun describes the second quadrant of the ecliptic F G H I K L, from ϖ to Δ , he will come later to the meridian every day than the star, which moves through the second quadrant of the equator, from f to ϖ ; for the points G, H, I, K, L, being farther from the meridian than the corresponding points g, h, i, k, l , they must therefore be later in coming to it; and as the sun and star arrive at the point Δ at the same moment, they must both come to the meridian at the moment of noon by the clock.

In departing from Libra, through the third quadrant, the sun going through M N O P Q towards ϖ , and the star through $m n o p q$, towards r ; the former will come to the meridian every day sooner than the latter, till the sun arrives at the point ϖ , and the star at the point r , and then they will both come to the meridian at the

the same time. And, in like manner, as the sun moves through the fourth quadrant S T U V W, from ν towards γ , and the star through the quadrant $s t u v w$, from r towards γ , the former will come later every day to the meridian than the latter, till they both arrive at the point γ , and then they will make it noon at the same time with the clock.

This part of the equation of time, may be made still more familiar by means of a globe; for if a small black patch be put on every tenth or fifteenth degree, both of the equator and ecliptic, beginning from the point γ , and the globe be turned round slowly to the westward, you will see all the patches from Aries to Cancer, come to the meridian sooner than the corresponding patches on the equator; all those from Cancer to Libra, will come to the meridian later than their corresponding patches on the equator; those from Libra to Capricorn sooner, and those from Capricorn to Aries later: whilst the patches at the beginning of Aries, Cancer, Libra and Capricorn, being either on, or even with those on the equator, show that the sun and star, either meet there, or are even with one another, and so come to the meridian at the same time.

Mr. Ferguson, whom I have chiefly followed in this article, proposes the following method for shewing the difference between solar, sidereal, and

and equal times. Suppose two little balls are made to move equally round a celestial globe, by means of clock-work; one always keeping in the ecliptic, and gilt with gold, to represent the real sun; and the other, keeping always in the equator, and silvered, to represent a fictitious sun; and let it be so contrived, that whilst these two balls move once round the globe, according to the order of the signs, the globe shall be made to turn three hundred and sixty-six times round its axis westward.

Then, as the motion of the globe is uniform, any fixed star will come to the meridian in equal times, and make in all three hundred and sixty-six revolutions, from the brazen meridian to the brazen meridian again. But the two balls, representing the real and fictitious suns, going continually farther eastward from any given star, will come later than that star to the meridian every following day than on the preceding one; so that each ball will make in all exactly three hundred and sixty-five revolutions; and they will both come together to the meridian at the beginnings of Aries, Cancer, Libra and Capricorn; but in every other point of the ecliptic, the gilt ball will come either sooner or later to the meridian than the silvered ball, in the same manner as the patches above-mentioned.

This is an easy way of shewing the reason why any given star, which, on a certain day of

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the year, comes to the meridian with the sun, passes over it so much sooner every following day, as on that day twelve month to come to the meridian with the sun again; and also, why the sun, moving in the ecliptic, comes to the meridian, sometimes sooner, and sometimes later than when it is noon by the clock; and on four days of the year at the same time; whilst a body, moving in the equator, would always come to the meridian exactly when it was twelve at noon by the clock. An ingenious artist might easily put this appendage to a celestial globe; for the gold ball might be carried round the ecliptic, by a wire from its north pole, and the silver ball round the equator, by a wire from its south pole, by means of a few wheels to each.

From what has been already said upon this subject, it is plain, that if the ecliptic cut the equator still more obliquely, as the dotted circle $\gamma \propto \triangle$, the equal divisions from γ to $\propto$, would come still sooner to the meridian $Z \gamma z$, than those marked A, B, C, D, E; for two divisions, containing thirty degrees, from γ to the second dot, a little short of the figure 1, come sooner to the meridian than one division, containing only fifteen degrees, from γ to A; whilst those of the second quadrant, from $\propto$ to $\triangle$, would be so much later. In the

Pl. VIII.
fig. 3.

third quadrant the same things would take place as in the first, and the fourth will be as the second; and where the ecliptic is most oblique, about Aries and Libra, it is evident, that the difference would be greatest; and least about Cancer and Capricorn, where the obliquity is least.

Having explained one cause of the difference of time, as shewn by a well regulated clock and a true sun-dial, I shall now proceed to the other, and endeavour to make that easy and intelligible. The obliquity of the ecliptic is not the only cause of an inequality in the length of days, but this inequality arises also from the unequal motion of the sun himself. This motion is slowest in summer, when the sun is farthest from the earth, and swiftest in winter, when he is nearest to it; as is evident from his staying longer in the northern half of the ecliptic than in the southern half, by about eight days: and therefore, although there were no obliquity of the ecliptic, the motion of the sun would not be a true and exact measure of time; for this motion sometimes exceeds a degree in twenty-four hours, and is sometimes less; and consequently when it is slowest, any particular meridian will come round sooner to him than when it is swiftest; so that the days, from this cause alone, could not be equal to each other.

If two bodies, therefore, were to move in the plane of the ecliptic, so as to go exactly round it in a year, the one describing an equal arc every twenty-four hours, and the other describing sometimes a less arc in twenty-four hours, and sometimes a greater, gaining at one time of the year what it lost at the opposite time; it is evident, that either of those bodies would come sooner or later to the meridian than the other, as it happened to be behind or before the other; and when they were both in conjunction, they would come to the meridian at the same moment.

Pl. VIII.
fig. 4.

This will be made plainer by a figure. For this purpose, let $A B C D$ be the ecliptic, or the elliptical orbit which the sun, by an irregular motion, describes in the space of a year; and the dotted circle $a b c d$ the orbit of an imaginary star that is coincident with the plane of the ecliptic, and in which the star moves through equal arcs in equal times. Let $H I K$, also be the earth, which turns round its axis, every twenty-four hours, the same way; and suppose the sun and the star to set out together from A and a , in a right line with the plane of the meridian $E H$; the sun at A , being at his greatest distance from the earth, at which time his motion is slowest; and the star at a , whose motion is equal, and its distance from the earth always the same.

Then,

Then, because the motion of the star is always uniform, and the motion of the sun, in this point of his orbit, is the slowest, it is plain that while the meridian revolves from H to H again, according to the order of the letters H I K L, the sun will have proceeded forward in his orbit from A to F; and the star, moving with a quicker motion, will have gone through a larger arc, from *a* to *f*. The meridian E H, therefore, will revolve sooner from H to *b*, under the sun at F, than from H to *k*, under the star at *f*; and consequently it will be noon by the sun, sooner than by the clock.

As the sun moves from A towards C, the swiftness of his motion will continually increase, till he comes to the point C, where it will be the quickest. But notwithstanding this, the star gains so much upon the sun, soon after his departure from A, that the increasing velocity of the sun does not bring him up to the equally moving star, till the former comes to C, and the latter to *c*, or when each has gone just half round its respective orbit; and as they are then in conjunction, the meridian E H, revolving to E K, comes to both the sun and star at the same time, and consequently it is noon by them both at the same moment.

From this point, the increased velocity of the sun being now the greatest, carries him before

the star; and therefore the same meridian will, in this situation, come to the star sooner than to the sun. For whilst the star moves from c to g , the sun moves through a greater arc, from C to G , and consequently the point K has its noon by the clock when it comes to k , but not its noon by the sun till it comes to l . And though the velocity of the sun diminishes all the way from C to A , and the star, by an equal motion, is still coming nearer to the sun, yet they will not be in conjunction till the one comes to A , and the other to a , and then it is noon by them both at the same moment.

From this it appears, that the solar noon is always later than the noon by the clock, whilst the sun goes from C to A ; and sooner whilst he goes from A to C ; and at these two points, the sun and clock being equal, it is noon by them both at the same time. The point A is called the Sun's Apogee; because when he is there, he is at his greatest distance from the earth; and the point C is called his Perigee; because when he is there, he is at his least distance from the earth: and a line AEC , drawn through the earth's center, from one of these points to the other, is called the Line of the Apfides.

It may also be observed, that the distance which the sun, at any time, has gone from his Apogee, and not the distance he has to go to

to it, though it be ever so little, is called his mean Anomaly; and is always reckoned in signs and degrees, allowing thirty degrees to a sign. Thus, for example, when the sun has gone a hundred and seventy-four degrees from his apogee at A, he is said to be five signs, twenty-four degrees from it, which is his mean anomaly. And so in like manner, when he is gone three hundred and fifty-five degrees from his apogee, he is said to be eleven signs, twenty-five degrees from it; although he be but five degrees short of A, in coming round to it again.

So that from what has been said, it appears, that when the sun's anomaly is less than six signs, that is, when he is any where between A and C, in the half of his orbit A B C, the solar noon will precede the clock noon: but when his anomaly is more than six signs, that is, when he is any where between C and A, in the half of his orbit C D A, the clock noon will precede the solar noon. On the contrary, when his anomaly is 0 signs 0 degrees, that is, when he is in his apogee at A; or, when it is exactly six signs, which is when he is in his perigee at C, he will come to the meridian at the same time with the star, and it will be noon by them both at the same instant.

The obliquity of the ecliptic to the equator, which is the first mentioned cause of the equation

tion of time, would make the sun and clocks agree on four days of the year, which, according to this illustration, are when he enters Aries, Cancer, Libra and Capricorn; but the other cause, now explained, would make the sun and clocks agree only twice a year, that is when he is in his apogee and perigee; and consequently when these two points fall in the beginnings of Cancer and Capricorn, or of Aries and Libra, they will concur in making the sun and clocks agree in those points. But the apogee, at present, is in the ninth degree of Cancer, and the perigee in the ninth degree of Capricorn; and, therefore, the sun and clocks cannot be equal about the beginnings of those signs, nor at any other time of the year, except when the swiftness or slowness of equation, resulting from one of the causes, just balances the slowness or swiftness arising from the other.

About the first of November, the absolute equation of time resulting from both these causes will be the greatest; the time shewn by an equally going clock being then about sixteen minutes and twelve seconds slower than the time shewn by the sun. And as this equation is of the utmost importance in all computations where time is concerned, astronomers have calculated tables, by which it may be found for every day of the year. By means of these
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tables we can always correct the apparent time, by reducing it to mean time, which is the principal end or object proposed.

For though the time shewn by the sun may be readily determined by observations, yet it is of no other use, but as it may be employed in finding the mean time, or that whose essence is equality or perfect uniformity. All the celestial revolutions, and every other epocha and period, are estimated by mean time; and, therefore, it is this only which ought to be used, as being the true and adequate measure of duration.

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L E T T E R XIII.

OF THE REFORMATION OF THE CALENDAR.

THE first care of every society, after providing for its most pressing wants and necessities, has always been to establish some uniform method of reckoning time. Without such a standard to refer to, as occasion requires, the administration of public affairs, and the common concerns of life, would be subject to perpetual confusion. A well regulated calendar is, therefore, a matter of the most extensive utility and importance. It is by this means, that we are able to ascertain the returns of the seasons, and to point out the proper times for cultivating the earth; to adjust the observance of civil and ecclesiastical institutions, and to transmit to posterity the dates of such events as are worthy of remembrance.

A computation of time by certain regular periods, is a custom that has been observed by all nations, where arts and sciences have been cultivated; but as nature has afforded us no fixed or permanent measure of duration, the manner of estimating those periods has been various and uncertain. In some countries the natural day is supposed to commence with the rising of the
sun,

fun, and in others with his setting ; some begin to reckon from midnight, and others from noon. The Jews and Romans divided the artificial day into twelve parts, whether long or short, and the night in the same manner ; so that their hours, except at the equinoxes, were always unequal ; which custom, notwithstanding its absurdity, is followed by the Turks to this day.

The week is another division of time, of the highest antiquity, which, in almost all countries, has been made to consist of seven days ; a period supposed by some to have been traditionally derived from the creation of the world ; whilst others imagine it was regulated by the phases of the moon. But whatever it might be, that led so many different nations to adopt this primitive measure ; it was certainly not universally received. The week of the antient Greeks, according to Gassendus, consisted of ten days, and that of the Romans of nine ; but afterwards, in imitation of the Jews, they divided it into seven ; which custom was first introduced among the Romans about the time of the emperor Theodosius. Dies Solis, Lunæ, Martis, Mercurii, Jovis, Veneris and Saturni, are the days of the Roman week, and the names of the seven planets ; and so, among us, Saturday, Sunday and Monday, plainly denote, Saturn's day, the Sun's day and the Moon's day ; and Tuesday, Wednesday, Thursday and Friday, are the days of Tuifco, Woden,

Woden, Thor and Friga, which are the Saxon names for Mars, Mercury, Jupiter and Venus.

But of all the divisions of time, which have been in general use, the month and the year are the most embarrassing. To determine these periods, with accuracy and precision, and to adjust them to the course of nature, is a matter of the utmost difficulty, and is yet far from being accomplished. The revolution of the moon in her orbit, or the time from one new moon to another, may be called a month; and the time the sun takes to perform his apparent course round the earth, from any one point in his orbit, to the same point again, may be called a year; but as neither of these revolutions are completed in an exact number of days, how are they to be reconciled with the common account of time, and made to agree with each other? The seasons are evidently regulated by the course of the sun; and as their returns are only to be known by means of his motion, it is from this alone that the proper length of the year can be determined.

In matters of little moment, the uninstructed part of mankind regard the powers of science with astonishment; but when the subject is beyond the reach of all science, they imagine it to be attended with no difficulties. This has been particularly the case, with the attempts that have been made to correct the vulgar methods
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of reckoning time. The populace of every country, consider the year as a certain regular period, the length of which is pointed out by nature herself; and, with a clamour that bids defiance to reason, oppose every alteration. To change the observance of certain religious feasts, which have been long fixed to particular days, is looked upon as an impious innovation; and though the times of the events, upon which those ceremonies depend, be utterly unknown, it is no matter; the Glastonbury thorn blooms upon Christmas-day, and this country has never flourished since that festival was altered.

Popular prejudices have been nearly the same in all ages. The ancient calendar was so obviously defective, that it was impossible not to perceive the disorder it occasioned; and yet the multitude were still averse to reformation. Aristophanes, in his comedy of the Clouds, has a number of pleasantries upon this occasion. An actor, who was just come from Athens, recounts that he met with Diana, or the moon, and found her extremely incensed, that they did not regulate her course better. She complained, that the order of nature was changed, and every thing turned topsy turvy. The gods no longer knew what belonged to them; but, after paying their visits upon certain feast-days, and expecting to meet with good cheer, as usual, they were under the disagreeable necessity of re-
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turning back to heaven again without their suppers.

Amongst the ancients, the length of the year was generally regulated by the course of the moon. This planet, on account of the different appearances she exhibits at her full and change, and at her quarters, was considered by them as the best adapted of any of the celestial bodies for this purpose. And as one lunation, or revolution of the moon round the earth, was found to be completed in about twenty-nine days and a half, and twelve of these lunations being imagined to be nearly equal to one revolution of the sun, their months were made to consist of twenty-nine and thirty days alternately, and their year of three hundred and fifty-four days. But as the time between two successive full moons is now known to be twenty-nine days, twelve hours, forty-four minutes, and three seconds, and the time the sun takes to move from one of the solstitial points to the same point again, is three hundred and sixty-five days, five hours, forty-eight minutes, and forty-five and a half seconds; it is evident, that this computation, although it agreed tolerably well with the course of the moon, must yet have been extremely defective, the difference between the lunar year and the true solar year, being more than eleven days.

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The irregularities which such a mode of reckoning would occasion, must have been too obvious not to have been noted. For, supposing it to have been settled, at any particular time, that the beginning of the year should be in the spring; in about sixteen years afterwards, the beginning would have been in autumn; and in thirty-three or thirty-four years, it would have gone backwards, through all the seasons, to spring again. This defect, however, they attempted to rectify, by introducing a number of days at certain times into the calendar, as occasion required, and putting the beginning of the year forwards, in order to make it agree with the course of the sun. But as these intercalations were generally consigned to the care of the priests, who, from motives of interest or superstition, frequently omitted them, the year was made long or short at pleasure, and the calendar was yet in a very imperfect state.

Several methods of correcting these errors, had been frequently proposed to the Roman senate, by the mathematicians of those times; but that people, intent only upon the aggrandizement of their empire, and extending the terror of their arms, had no leisure for the peaceful pursuit of science, and were long ere they aspired to the glory of being learned and enlightened. Julius Cæsar was the first among them, who, to his other extraordinary qualities, added

added an eminent knowledge of the sciences of astronomy and mathematics.

Amidst the hurry of tumultuous war,
The stars, the gods, the heav'ns, were still his care ;
Nor did his skill to fix the rolling year,
Inferior to Eudoxus' art appear.

L U C A N.

The state of the calendar particularly engrossed his attention, and being soon convinced of its irregularity, he was immediately determined to reform it. To assist him in this undertaking, he made choice of Sosigenes, a celebrated mathematician of Alexandria in Egypt ; who found, that the dispensation of time could never be settled upon any sure footing, without having regard to the annual revolution of the sun ; and as this revolution is found to be completed in three hundred and sixty-five days, and about six hours, he made the year to consist of three hundred and sixty-five days, for three years successively, and every fourth year of three hundred and sixty-six, in order to take in the odd six hours.

This reformation was made in the year of Rome 708, about forty-five years before the birth of Christ ; and as it was computed that near ninety days had been lost by the former method of reckoning, these were now taken into the account, and the first Julian year was made to consist

consist of four hundred and forty-four days. After this, the beginning of the year was fixed to the first of January, and the months were divided into the same number of days as they are at present. The odd day, which arises out of the six hours above-mentioned, was introduced into the calendar every fourth year, by reckoning the twenty-fourth of February twice over; and as this day, in the old account, was the same as the sixth of the calends of March, which had been long celebrated on account of the expulsion of Tarquin, it was called, his Sextas calendas Martii; from which we have derived our name of Bissextile, or Leap-year.

Julius Cæsar was born upon the fourth of the ides of the month Quintilis, and after his death, Marc Antony, who succeeded him in the consulship, ordained that the name of this month should be changed to that of Julius, in honour of his predecessor. The name of the month Sextilis was also changed to that of Augustus, in memory of the emperor of that name; and these appellations have been retained ever since. But Nero, who had given his name to the month April, and Domitian, who had given his to the month October, were soon deprived of these honours; for after the death of those tyrants, their names were taken from the calendar, and the former ones reinstated.

The Julian account, as this method of reckoning has since been called, though far superior to any that preceded it, was, however, still imperfect: for as the time in which the sun performs his annual revolution is not exactly three hundred and sixty-five days, six hours, but three hundred and sixty-five days, five hours, forty-eight minutes, and forty-five and a half seconds, the civil year must, therefore, have exceeded the solar year by eleven minutes, fourteen and a half seconds; which in the space of about one hundred and thirty years amounted to a whole day: and, consequently, in forty-seven thousand four hundred and fifty years, the beginning of the year would have advanced forwards through all the seasons; so that in half this space of time the summer solstice, according to the calendar, would have fallen in the midst of winter, and the earth been covered with frost, when the bloom of vegetation was expected.

It is not to be imagined, that Sosigenes was totally unacquainted with this error; but he probably thought it much smaller than it really is, and on that account neglected it. The true length of the solar year had not yet been accurately determined; and as it was only from a sensible anticipation of the seasons, that the civil reckoning could appear defective, the Julian account was long considered as perfectly consonant with the course of nature; and all the

states of Europe confided in it, as one of the most exact and just estimations of time that could possibly be devised. Some irregularities were occasioned, soon after the death of Cæsar, by the negligence of the pontiffs, who had not observed the established method of intercalating the odd day; but from the time of Augustus, who corrected these errors, to about the middle of the sixteenth century, it does not appear that the calendar had been subject to any alteration.

Among the first of those who discovered its imperfections, were the venerable Bede, Sacro Bosco, and our countryman Roger Bacon. Those great men, who were the ornaments of the times in which they lived, had observed that the true equinox preceded the civil one, by about a day in a hundred and thirty years. And as the council of Nice, which was held in the year 325, had fixed the vernal equinox to the twenty-first of March, it was accordingly found, that from that time to the year 1582, when the next reformation was effected, the error accumulated by this means, amounted to about ten days; so that the vernal equinox was now found to happen on the eleventh of March, instead of the twenty-first, as it ought to have done, had the Julian account agreed with the course of the sun.

This constant anticipation of the equinox, which, in the course of more than a thousand years, had become too obvious not to be

noticed, was first represented to the councils of Constance and Latran, by two cardinals, Ailli and Cusa, who shewed the cause of the error, and the means of correcting it. And in the year 1474, Pope Sixtus IV. being convinced of the necessity of a reformation, sent for Regiomontanus, a celebrated mathematician of that time, to Rome, and presented him to the archbishoprick of Ratibone, in order to engage him in this undertaking. But a premature death preventing his assistance, and no one being thought worthy to be his successor, the project was, for that time, suspended.

The necessity of some alteration, was, however, still insisted upon: and about a hundred years afterwards, Pope Gregory XIII. had the honour of accomplishing what several preceding pontiffs and councils had attempted in vain. A plan, which was presented to him by Aloisius Luilius, a Veronese physician and astronomer, after being examined by the most able mathematicians of that time, was sent to all the princes in Christendom, for their advice and assistance: and as the execution of it appeared to be attended with little difficulty, it met with general approbation. A council, therefore, of the most learned prelates, was convened by the pope, and the subject being finally settled, a brief was published in the month of March, 1582, by which the use of the ancient calendar

was entirely abrogated, and the new one substituted in its stead.

This was called the Gregorian account, or New-Style; and as it is that which is at present in use throughout the greatest part of Europe, I shall endeavour to give you as familiar an account of it as possible. The first object of the reformers, was to correct the errors of the former method of reckoning, and to make the length of the year agree more exactly with the course of the sun. For this purpose it was agreed, that the ten days, which had been gained by the old account, should be taken from the month of October of the year then current, and the equinox brought back to the twenty-first of March, as it had been settled by the Nicene council. And, that a like variation might not happen in future, it was ordered, that instead of making every hundredth year a biffextile, as was the case in the former method, every four-hundredth year only should be considered as a biffextile, and the rest be reckoned as common years.

The length of the solar year, and the time of the vernal equinox, were by this means very accurately settled; for as a day was gained, by the former method of reckoning, in every hundred and thirty years, this was nearly equivalent to a gain of three days in every four hundred years; and consequently, by making the years 1700, 1800, and 1900, to be common

years instead of leap-years, the error arising from the odd time would be properly corrected. But this was a part of the subject that was easily accomplished; the great difficulty consisted in making the lunar year agree with the solar one, and in settling the true time for the observance of Easter, and other moveable feasts, which had hitherto been subject to no regular rule.

It was ordered by the council of Nice, that Easter should be celebrated upon the first Sunday, after the first full moon, following the vernal equinox. And in order that this rule might be properly observed, it became necessary to know the days when the full moons would happen, in the course of every year. But this was a knowledge that was not easily obtained; for the period of Meton, which made nineteen years exactly equal to two hundred and thirty-five lunations, or revolutions of the moon, was found to be too long by about one hour and thirty-two minutes: and consequently, after sixteen of these periods, the true phases of the moon would precede those shown by the calendar, by more than a whole day.

At the time when the Gregorian account first took place, the error occasioned by this means amounted to four days; and had the old method of computation prevailed, the calendar, in time, would have announced the full moon at the time of the change, and Easter would have been cele-

celebrated at a period directly opposite to that established by the church. To correct these errors, therefore, it was necessary that some other method should be devised, than that which had been hitherto in use; and as the nineteen years of Meton had a particular property, which had not yet been noticed, Luilius had the good fortune to discover it, and to make it subservient to the purposes required.

The new and full moons, which according to Meton, were imagined to happen at exactly the same time as they had nineteen years before, were usually indicated in the following manner; they observed on what day of each calendar month the new moon fell, in each year of this period, and against those days they placed the number answering to that year, reckoning from one to nineteen, through all the years of the cycle. And those numbers, on account of their great usefulness, were called Primes, or Golden Numbers; but as Luilius found them to be erroneous and inconvenient, he rejected them from his system, and made use of others, called Epacts, in their stead.

The epact, is the difference between the solar year and the lunar one; or the moon's age at the end of the year. But, in order that this may be better understood, I shall illustrate it by an example. Suppose, therefore, that at any particular time, the new moon was to happen

upon the first of January, the epact for that year would then be nothing. And as twelve lunations are completed in three hundred and fifty-four days, it is plain, that the epact, or moon's age, at the beginning of the second year, would be eleven; at the beginning of the third year, twenty-two; and at the beginning of the fourth, thirty-three. But as the time of one lunation is never more than twenty-nine days and a half, the epact cannot possibly exceed thirty; in this case, therefore, thirty must be subtracted; so that instead of thirty-three, at the beginning of the fourth year, the epact will be only three. And by observing this rule, through a period of nineteen years, the epacts will stand in the following order, 0, 11, 22, 3, 14, 25, 6, 17, 28, 9, 20, 1, 12, 23, 4, 15, 26, 7, 18.

These epacts being placed against the days of the month in the calendar, on which the new moons fell in each year, would have answered the same purpose with the golden numbers; and had the Metonic cycle been complete, the form would have required no alteration: but this is not the case; for after about sixteen of these periods, or three hundred years, the new moons, arriving sooner by twenty-four hours, would happen on the preceding day; and therefore the epacts answering to those new moons, ought to be augmented by unity. For supposing, that the second year of the lunar cycle had eleven for
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the epact, then because the new moon, the preceding year, arrived eleven days before the end of December, after three hundred years, the same new moon, of the first year of the cycle, would arrive twelve days before the end of the year; and, consequently, the second year ought now to have twelve for the epact.

This number twelve, therefore, will be the index of the new moons in that second year; and it is easy to perceive, that all the new moons which happen sooner by a day, will take place upon the day preceding that which in the former period was marked eleven. After three hundred years more, the epact will be thirteen, which will be a day still preceding that in the latter period: and the same will happen with all the other epacts of the cycle. It was this kind of analysis, that gave Luilius the idea of placing the epacts in their natural order, against the days of the new moons in every year, for the first three hundred years; and after that period, to place them in the order 1, 12, 23, 4, 15, 26, 7, 18, 29, 10, &c. instead of the former one; and so on.

This arrangement was simple and ingenious; but the omission of three days in every four hundred years, was a circumstance that occasioned some embarrassment. These years, having a day less than in the Julian account, the new moons would happen a day later, and consequently the epact, at the end of the year, must

must be diminished accordingly. But as this order is only interrupted once in a hundred years, Lullius imagined, that by subtracting unity from each of the epacts belonging to those new moons, they might be made to serve for the subsequent century. And as there are only thirty possible series of these numbers, it was sufficient to shew by a table, what series belonged to every century; by which the times of the new moons might be readily discovered.

This is a concise account of the Gregorian reformation; and if you are desirous of entering more fully into the subject, I must refer you to works written expressly upon it; for to have given a minute detail of every particular, would have required a large volume. What has been said, will enable you to form a general idea of this intricate business, which, as the matter is now fully settled, is all that is requisite. It only remains just to mention, what reception this alteration of the style met with, from the different states of Europe.

Pope Gregory ordered all the ecclesiastics under his jurisdiction to conform to this new method of reckoning, and exhorted the christian princes to adopt it in their dominions. But the protestant states, at that time, refused it; the reformed religion was in its infancy; the zeal of its professors was violent, and their opposition to the pope unbounded: whatever bore the
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appearance of his authority, was rejected as an unwarrantable encroachment upon their newly-acquired liberties; and though the propriety of the alteration was acknowledged, it was condemned, on account of its originating with a party so extremely obnoxious to them.

But the difference between the old and new style, as the Julian and Gregorian accounts are generally called, occasioned great confusion in the commercial affairs of the different states of Europe. In England, particularly, this inconvenience was considerably felt, and several attempts were made to introduce the reformed calendar; but popular prejudices were too strong, to be easily overcome. The mathematicians, indeed, more influenced by scientific considerations, than cavils about points of religion, were continually urging the necessity of some correction, and proposed several methods of obtaining it, which might be adopted without inflaming the minds of the multitude.

One of the most simple and ingenious of these, I shall just mention; which was, that an act should be passed, declaring, that there should be no leap-year for forty years to come; by which means, the ten days, that had been gained by the old account, would have been imperceptibly lost, and the old style reduced to the new, without any sensible variation in the fixed time of feasts, and other observances. A proposal

posál of this kind was sent to Dr. Wallis, then professor of geometry at Oxford, for his opinion: but the doctor, with a narrowness of sentiment, which could scarcely have been expected from a man of his extensive erudition, observed, that the proposál was specious enough in appearance, but that the hand of Joab might be perceived in it. He imagined it to have originated with the papists; and though he acknowledged its propriety, was yet afraid of its being adopted, lest it should open the door to further encroachments.

But though all proposáls were at that time rejected, yet those who wished for a reformation, still continued their applications; and in 1752, an act of parliament, after much debate, was obtained for this purpose. And as a hundred and seventy years had elapsed, since the Gregorian alteration took place, the old style had consequently gained above a day more upon the course of the sun than it had at that time; it was therefore enacted, that instead of cancelling ten days, as had been done by the pope, eleven days should be left out of the month of September; and, accordingly, on the second of that month, the old style ceased, and the next day, instead of being the third, was called the fourteenth.

It may be observed, however, that the Gregorian reformation met with many opponents from men of science; Mæstlin, Scaliger, Vieta,
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and other mathematicians, attacked it with great violence, and proposed methods of their own, which they considered as less exceptionable. But Clavius, to whom the care of this business was assigned, after the death of Lilius, composed a large work in its vindication, and victoriously combated all his adversaries. Some defects, however, it must be acknowledged, are to be found in this method; but the task of reformation was difficult; the reformers had to chuse among a number of inconveniencies, and they preferred the least considerable: we ought, therefore, to applaud them for their skill, rather than to censure them for defects, which no human abilities could have wholly avoided.

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L E T T E R XIV.

OF THE MENSURATION OF THE EARTH.

TO measure the earth, and from thence to determine its magnitude and figure, is one of the most astonishing enterprizes, that ever was undertaken by man. Confined to a particular spot, without any other scale or model than his own proper dimensions, how is he to find the distances of places which he can never visit, and to embrace the vast circumference of the globe? The space he has passed through, may be estimated by the number of steps he has taken, and this will furnish him with the most simple measures, the foot and the yard; the cubit is the length of his arm, from the elbow to the end of the middle finger; and the fathom, or toise, is the height of his stature; but what are these small measures, in comparison to the perimeter of the earth? They are but as a grain of sand to the largest mountain. Difficulties, however, serve but as incitements to action; and man, instead of being confounded by the inadequacy of his natural powers, finds a resource in his intelligence, that supplies their defect;

defect; he multiplies small measures, till he arrives at the greatest; and forms to himself an unit, to which he refers all the parts of the universe.

By means of chains and cords, which are certain multiples of the toise, or the yard, he obtains an artificial measure more convenient than the natural one; and with this new standard, repeated a certain number of times, in the same manner as before, he forms furlongs, miles and leagues; and undertakes to measure such distances, as would be otherwise indeterminable. But this method, is yet totally inadequate to the purpose required; for if it were necessary for us to follow the whole circumference of the earth, in order to obtain its measure, the thing would be impossible; mountains, rivers, and seas, would be perpetual obstacles in our way; and uninhabitable climates would put an entire stop to our progress. What, then, is to be done? Astronomy furnishes us with the means of conquering all these difficulties; the agreement which is observed between the heavens and the earth, provides us with a method of measuring the whole terraqueous globe, without the necessity of quitting our country, or even losing sight of our native habitations. The celestial vault which is over our heads, is exactly similar to the spherical surface of the globe; so that by knowing the measure of a degree in
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the heavens, we can find the measure of a corresponding degree upon the earth; and this being once determined, an obvious relation will give us the measure of the whole.

Let us leave this part of the subject for the present, and attend to the steps that led to so important a discovery. I have given you some account, in a former letter, of the whimsical opinions entertained by the ancients concerning the figure and magnitude of the earth; and, from enquiry, we shall find, that some of the most learned modern writers, though not altogether so absurd in their notions, have yet but little superiority to boast of in other respects. Many great philosophers, and doctors of the church, even to the fifteenth century, imagined the earth to be a flat body, infinitely extended, and covered by the sky, in the form of a vault or tent. This opinion appeared to them so much the more probable, as they believed it to be founded upon the Bible. But a very little time before the discovery of America, a bishop of Avila treated the notion of the earth's having a globular form, as an impious absurdity. At length, reason, and the voyage of Christopher Columbus, restored to the earth its spherical figure, which the ancient Egyptians and Chaldeans had given to it; and it was now generally believed to be a perfect globe,

and that the stars made their revolutions round it in a true circle.

Of this opinion were the greatest philosophers of the age; a globe is the most perfect of all geometrical figures, and the observed simplicity of nature, in most of her operations, seemed to favour the idea of the earth's having such a figure. This imaginary simplicity, however, proved to be a false light, that misled its followers. Mr. Richer, in a voyage made to Cayenne, near the equator, undertaken by order of Lewis XIV. under the protection of the great Colbert, among many other observations, found that the pendulum of his clock no longer made its vibrations so frequently as in the latitude of Paris; and that it was absolutely necessary to shorten it by a line and a quarter, or a little more than the eleventh part of a Paris inch, in order to make it agree with the times of the stars passing the meridian.

Natural philosophy and geometry were not then by far so much cultivated as they are at present; and who could have believed, says Mr. Voltaire, that from an observation so trifling in appearance, that from the difference of about the eleventh part of an inch, could have sprung so sublime and philosophic a truth. A pendulum, like any other falling body, is acted upon by the force of gravity; and in consequence of Richer's discovery, it was observed,

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that, since the gravity of bodies is by so much the less powerful as those bodies are farther removed from the center of the earth, the region of the equator must absolutely be much more elevated than that of France; and that, therefore, the figure of the earth could not be that of a sphere.

This reasoning, so very simple and natural, escaped the greatest philosophers of that time; a certain proof, that the strength of prejudice does not permit even the slightest examination: they even contested Richer's experiment. Metals are known to be lengthened by heat, and contracted by cold, and to this cause they attributed the difference he had observed between the vibrations at Cayenne and at Paris. The most intense summer heat will lengthen an iron rod of thirty feet long, about the eleventh part of an inch; but the question here was concerning an alteration, which was afterwards found to be nearly twice as great as this, in a rod of little more than three feet in length; and therefore this dilatation must have been owing to some other cause than that of heat.

Some years after this, Mess. Deshayes and Varin, who were sent out by the French king, to make certain astronomical observations near the equator, found that the pendulum at Cayenne, required to be shortened much more considerably than had been mentioned by Richer. He

had observed, that it made a hundred and forty-eight vibrations less in a day than at Paris, and that his clock was retarded, by that means, two minutes and twenty-eight seconds; but Mr. Deshayes found a much larger difference, and was obliged to make his pendulum shorter by two lines, in order to make the time agree with that which was deduced from celestial observations. This difference between the two observers may be easily accounted for; Richer was struck with the singularity of the phenomenon, and, as is natural upon such occasions, examined it with timidity. He doubted whether he might not be deceived by his own senses, and endeavoured to see the least variation possible.

This experiment has since been absolutely confirmed by the French academicians, in the account they have given of their expedition to Peru, in South America. They inform us that about Quito, at a time when it froze, they were obliged to shorten the pendulum for seconds about two lines, or the sixth part of an inch; which puts it out of all doubt, that the alteration could not be occasioned by heat. The same phenomenon has likewise been observed at Martinique, at St. Domingo, at St. Helena, and at Goree, upon the coast of Africa, near the Cape de Verd islands; in all which places it was found, that the alteration was the greatest under the

equator, and that it diminished as the observer approached towards the northern climates.

The observations made at Cayenne, might have been considered as too local and particular to have admitted of any satisfactory conclusion; but as a like alteration was found to take place in so many different situations, we can no longer hesitate in receiving it as a general phenomenon, arising from an actual diminution of gravity, in those places where the experiment was performed. This discovery, trifling as it may seem, opened a new field of speculation to philosophical minds; and there are, perhaps, few or no facts, in the whole circle of the sciences, from which so many curious and useful consequences have been derived. Some of the greatest mysteries in nature began now to be unveiled. The experimentalist performed his operations, the philosopher formed conjectures, and the mathematician demonstrated truths as sublime and important, as they were new and surprizing.

Those great men, Newton and Huygens, were the first who perceived the extensive application of which this discovery was capable. They seized the new truth with avidity; and, by following it through all its consequences, obtained the solution of a problem, which seems beyond the reach of human abilities. This was no less than the determination of the true figure of the earth,

earth, which they actually discovered from mathematical considerations only; and notwithstanding all the light that has been since thrown upon this subject, both from an actual mensuration of the earth, and from the laborious researches of some of the first philosophers in Europe, the measure of Newton is considered as so accurate, that it is still used in preference to all others.

To enter into all the calculations that were employed in this enquiry, would be foreign to my purpose. I shall only give you an account of the principles upon which they were founded, and leave the rest as a subject for your more mature consideration and reflection. It is a known property of the pendulum, that all its vibrations are made in the same time; and that the time in which each vibration is performed, is in proportion to the square root of the length of the rod: thus, a pendulum of thirty-six Paris inches in length, makes its vibrations in a second; and one of nine inches, makes its vibrations in half a second; so that the shorter the pendulum, the swifter it moves; and the longer it is, the slower it moves; the ratio being always the same as that before-mentioned.

The time, therefore, in which any pendulum performs its oscillations, depends as well upon the length of that pendulum, as upon the force that impels it towards the surface of the earth.

If this force be diminished, by any cause whatever, the body, with a less capacity for motion, will employ a longer time to move through the same space; and in order that each vibration may be made in the same time as it was before this diminution took place, the length of the rod must be shortened, by which a new velocity may be given to it that will be sufficient to supply the defect. This was exactly the case, in the experiments made at Cayenne, and other places near the equator; the observers were obliged to shorten the rods of their pendulums, in order to make them perform their vibrations in the same time as at Paris; and from this it was properly inferred, that gravity, or the force that occasions their descent, had actually suffered a real diminution.

But by what case is it, that gravity is less powerful under the equator, than at London or Paris? This is the question, upon which every thing relating to this subject depends. Sir Isaac Newton considered it in the following manner. The diurnal rotation of the earth is performed round an imaginary line, that passes through the two poles; and as the equator is farther distant from its center, than any other circle which is parallel to it, it is plain, that those parts of the earth which lie under the equator, will move with a greater velocity than those which are nearer to the poles; and of course,
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the equatorial regions will become more elevated than the polar ones; so that if the earth were an entire fluid, and the waters met with no obstacles in their progress, they would recede from the poles towards the equator, and by that means flow in continually till they had formed an equilibrium, and could rise no higher.

This tendency of bodies to fly off from the center round which they move, is called the centrifugal force, the nature and existence of which, may be made evident in a number of ways. When a mop is turned upon the arm, by a quick circular motion, the threads, or thrumbs, are observed to rise highest in the middle; and the swifter the mop is whirled, the greater will be the force, and the particles will fly off with the greater velocity. The same thing is observable, when a stone is turned swiftly round, by means of a fling; the arm finds itself stretched by a considerable force, which force is exerted upon it by the stone, in its endeavours to recede from the center; and if the stone be disengaged from the fling, by a sudden stop of the hand, it will immediately manifest the tendency which it has to leave this constrained circular orbit, by its proceeding directly forwards in a straight line.

Besides this, there is another force, which is called centripetal; and is so denominated, because it is directed towards the center, and acts in

direct opposition to the former. This force, in the present case, is the same as gravity; the nature of which may be thus explained. All heavy bodies, when left to themselves, are observed to fall towards the earth in straight lines, which are perpendicular to the horizon; and if those lines were continued, it is plain from the nature of a globe, that they would all pass through the earth's center. Every part of the earth, therefore, gravitates towards the center; and as this force is found to be about two hundred and eighty-nine times greater than the opposite one, or that which arises from the rotation of the earth upon its axis, a certain balance will constantly be maintained between them, and the earth will assume such a figure, as would naturally result from the difference of these two contrary and opposite forces.

It is well known, that if an exact beam, or rod, be suspended in the middle, and left at rest, the cords which sustain the equal scales, or weights, that are hung at its two extremities, will take such situations as are perpendicular to the horizon; or, which is the same thing, such as tend directly towards the center of the earth. But if a circular motion be given to this balance, the center of which is the point of the beam's suspension, we shall immediately see that the scales will fly out of the perpendicular lines, in proportion to the velocity of the circular motion;

motion ; so that the cords will no longer follow the usual direction of gravity, towards the center of the earth, but will take such oblique situations, that the scales, or lower extremities, will be farther apart than any other two corresponding points of the cords.

This illustration is applied by Mr. Voltaire to the figure of the earth. Let us conceive, says he, a great curvilinear balance, whose middle is suspended to one of the poles, and whose extremities, or weights, extend to an equal elevation on both sides the equator ; then it is evident, that if the earth, which we are now examining, turns upon its axis, and carries this curvilinear balance round with it, by a circular motion, the weights, which before were at rest, and inclined towards the center of the earth, will be now removed from this inclination, out of the perpendicular lines on both sides, and will fly off to a greater distance at the equator, than at any other parts of the balance which are nearer to the poles. So that from this circumstance, the figure of the earth, arising from its rotation on its axis, is sufficiently manifest.

It was from circumstances of this kind, but in a way more mathematical and scientific, that Sir Isaac Newton founded his sublime calculations upon this interesting subject ; and, as Mr. Fontenelle observes, determined the true figure
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of the earth without quitting his elbow-chair. The experiments of Richer, at Cayenne, first attracted his attention; and by applying himself to the subject, he soon perceived the reason of all the phænomena which that gentleman had discovered. As gravity is the same upon all parts of the earth, and the centrifugal force is greatest at the equator, it is plain, that the action of such a force must diminish the weight of bodies, and occasion them to fall with a less velocity at the equator, than in places nearer to the poles.

Newton and Huygens were both engaged in these enquiries at the same time, and the result of their calculations were nearly the same: they each of them separately considered, that this diminution of gravity, which manifests itself in such bodies as are detached from the earth, and left to themselves, must also have the same influence on the constituent parts of the earth, which, by their mutual coherence, compose the solid mass of the globe. From this obvious principle, which is agreeable to universal experience, it was discovered, that the centrifugal force at the equator is about a two hundred and eighty-ninth part of the force of gravity; and that a body weighing two hundred and eighty-nine pounds at the pole, would weigh only two hundred and eighty-eight at the equator.

It has been estimated, that about three quarters of the surface of the earth are covered by the ocean ; and as it is the nature of fluids, for their particles to be easily moved among themselves, they must always be ready to yield and give way to the slightest impression. That diminution of weight, therefore, which arises from the action of the centrifugal force, will easily manifest itself in all fluids ; and as it has been shewn, that gravity acts less powerfully at the equator than at the poles, the waters will of course flow towards the equatorial regions, in order to balance those at the poles. But this elevation is not confined to the waters of the ocean ; the solid parts of the globe must also be subject to the same force ; for if the lands which lie under the equator were not elevated in the same proportion with the waters, the ocean, leaving its bed, would submerge the continent, and the greater part of the torrid zone would be nothing but one continued sea.

This revolution, however, has not taken place. The East and West Indies, and a great part of the vast continents of Africa and America, lie in the neighbourhood of the equator, and are sufficient proofs, that the earth rises to defend itself against the invasions of the ocean. Every part of the globe, therefore, from the center to the circumference, is subject to the
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action of a centrifugal force; and supposing the primitive figure of the earth to have been that of a globe, which is the shape it would naturally assume from the mutual attraction of its constituent parts, this force, or the action arising from a constant rotation upon its axis, would evidently change it into an oblate spheroid, or a figure nearly resembling that of an egg. This was the figure determined by Newton, who found, by mathematical calculations, that the polar diameter of the earth is to the equatorial, as two hundred and twenty-nine is to two hundred and thirty; or, that the regions of the equator are elevated about thirty-five miles more than those at the poles.

Who could have imagined, that such a simple circumstance as the retardation of clocks in certain climates, and the necessary shortening of the pendulum, would have given birth to such a grand and important discovery, as that of the true figure of the earth! But such is the wonderful connection and secret dependence of things; nature is uniform in all her operations, and it is her peculiar excellence, that she often produces the greatest effects from the most apparently trivial causes. To discover this hidden correspondence, is the privilege only of superior minds; and such is the ignorance and envy of the multitude, that the man who first announces these

these truths to the world, is often considered as no other than a troublesome innovator of new doctrines, which serve only to disturb the peace and happiness of mankind. Newton, the great father of philosophy, was more happily circumstanced; he had the good fortune to live in an enlightened age, when bigotry and superstition were every day losing ground: his genius set him at such a height above the rest of mankind, that but few, even amongst the learned, could understand him; they admired his researches, but doubted the truth of his conclusions. Il a fallu (says *Monf. Bailly*) du tems & de longues études pour comprendre Newton, & se rendre digne de recevoir ses leçons.

The figure of the earth, however, is a mathematical truth, which is confirmed by experience. By means of a good telescope, it is easy to perceive, that the planet Jupiter is flattened about his poles, in nearly the same manner as has been asserted of our earth. What exists in one planet is possible in another; and as it is reasonable to conclude, that matter is every where endowed with the same properties, it is natural to infer, that the same force which has compressed the globe of Jupiter, has also occasioned a like alteration in our earth. Jupiter is composed of a heavy matter, which is capable of attracting his satellites in the same manner as our earth
attracts

attracts the moon ; but as his rotation upon his axis is performed with a greater rapidity than that of our earth, so the alteration in his figure is found to be much more considerable, as would naturally follow from such a motion. The relation of his diameters, according to Newton, is nearly as twelve to thirteen, and the difference between his equatorial and polar diameters is about six thousand two hundred and thirty miles.

LET.

LETTER XV.

THE SAME SUBJECT CONTINUED.

LET us now quit the researches of Newton, and see how far his mathematical deductions have been confirmed by experience. This is the true test of all hypothetical reasoning, and is what he himself lays down as the basis or foundation of every philosophical enquiry. The great utility and importance of this interesting subject, was far from being unknown to the ancients. We are assured from the testimony of Herodotus, and other early historians, that attempts had been made to discover the true figure of the earth, by many of the most celebrated mathematicians of antiquity: Ptolemy, in his *Almagest*, has preserved the measures of Hyparcus, Eratosthenes and Posidonius, who all lived before the time of Christ; and from what Mr. Bailly has advanced in his *Histoire de l'Astronomie Moderne*, it appears highly probable, that this singular enterprise had been undertaken in the still more remote ages of the world.

But as all the determinations of the ancients are uncertain, on account of our not knowing

ing the length of their stadium, or principal measure, I shall pass over the peculiar methods and operations they employed, and proceed to those of the moderns, which, in the present improved state of the sciences, must be infinitely more exact and scientific. Riccioli attempted to measure the earth according to a method mentioned by Kepler. It was known from observation, that heavy bodies, in falling, tend towards the center of the earth. And as the distance of any two places upon the surface of the earth is the base of a triangle, whose vertex is at the center, he measured a large base of this kind, in the most accurate manner possible, and took the angles which it made with a plumb line at each of its extremities, with an instrument proper for that purpose. The sum of these angles, by a property in geometry, being taken from a hundred and eighty degrees, gave him the angle at the vertex; and as he had now an angle at the center of the earth, and the length of a base line upon its surface, which answered to it, it was easy, by the rule of proportion, to find the length of the whole circumference. For, by the property of the circle, as the degrees in this angle are to the length of the base, so is three hundred and sixty degrees to the circumference required.

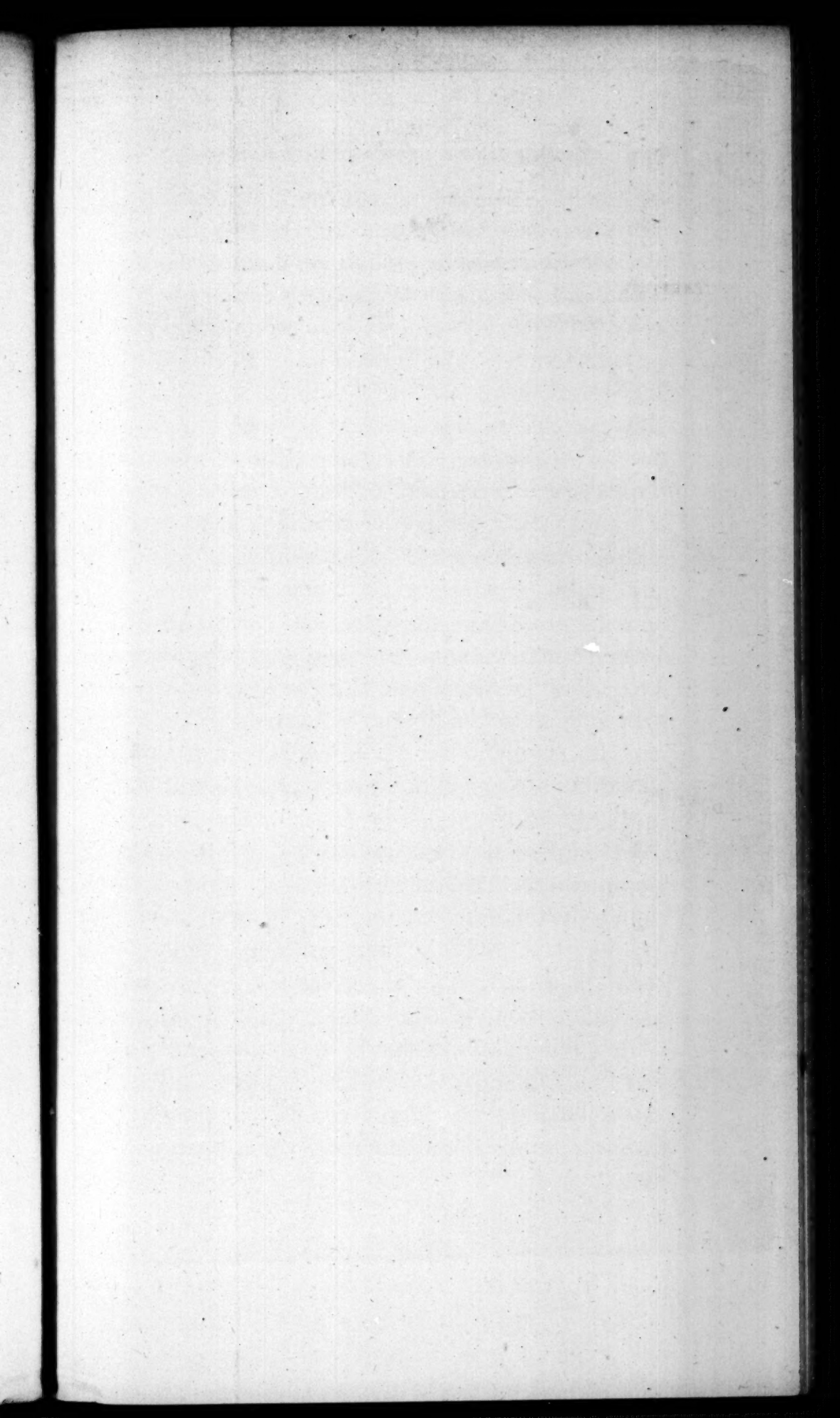
This method of Riccioli is more ingenious than accurate; he wanted to measure the earth, without

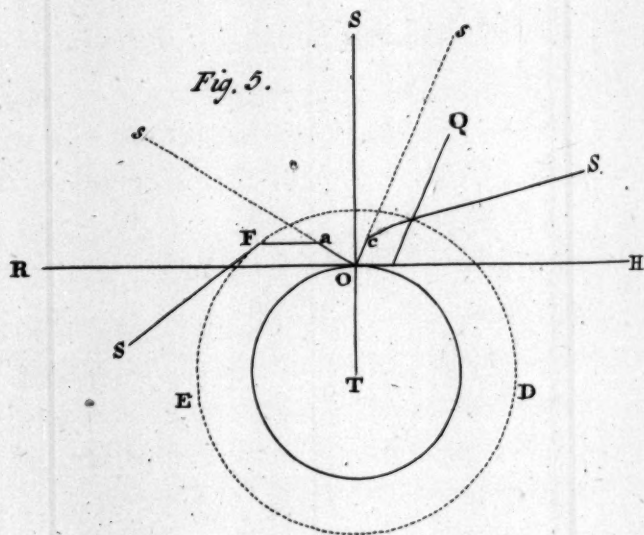
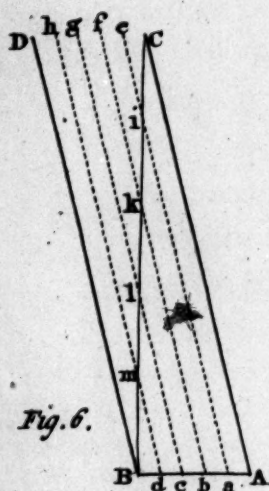
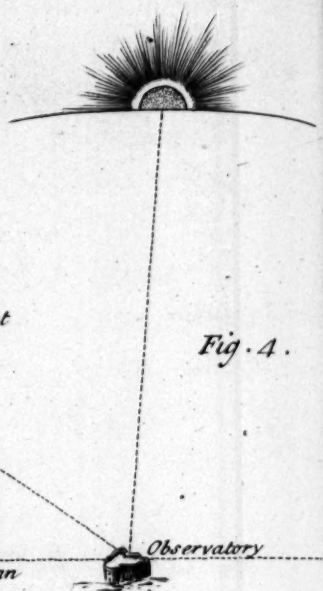
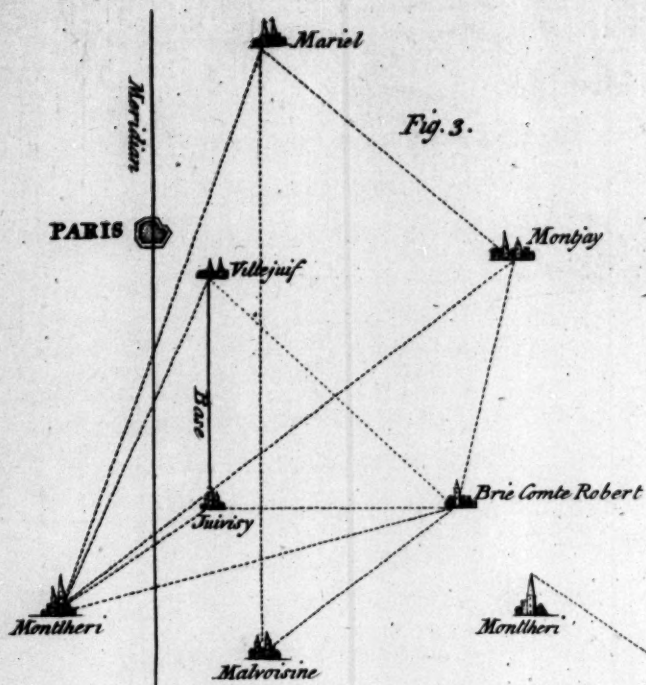
without having recourse to celestial observations; but this independence, to which he aspired, was not to be obtained. Order and regularity are only to be found in the heavens; and it is to them we are indebted for almost all we know of the earth. We are deceived by every thing around us; even our senses mislead us; and what we think ourselves the best acquainted with, is frequently proved to be an illusion. Objects seen at a distance never appear in their true places; they are always more or less elevated, according to the season, and hour of the day; and this error is unknown, because it varies incessantly with the atmosphere that surrounds us; which prevents us from being able to determine either their true height, their direction, or the angle at the center, which depends upon this direction. This determination should be made with a rigorous precision, before we can deduce the vast circumference of the earth, from such small measures as we are able to take on its surface. Riccioli was accordingly mistaken near six thousand toises in the length of a degree.

The next who attempted to find the circumference of the earth was Snellius, a German. He measured the distance between Alcaer and Bergen-op-zoom; and by taking the celestial arc, which corresponds to this distance, with proper instruments, he found the length of a degree to

be fifty-five thousand and twenty-one toises. But the person who engaged in this enterprize with the most success, was Norwood, an Englishman. In the year 1635, he took the sun's altitude, when it was in the summer solstice, both at London and York, with a sextant of five feet radius, and by that means found the difference of latitude between these two cities to be two degrees and twenty-eight minutes. He then measured their distance, in the most exact manner possible; and having taken into the account all the turnings and windings in the road, with the ascents and descents, he reduced it to an arc of the meridian, and found it to contain twelve thousand, eight hundred and forty-nine chains; and this distance, compared with the difference of latitude, gave him five thousand, two hundred and nine chains to a degree, or about fifty-seven thousand three hundred French toises.

This method will want no explanation, if the two places be considered as lying under the same meridian, which indeed is nearly the case; for then the terrestrial and celestial arcs will exactly correspond with each other, and the relation of either of them to the whole circumference will be readily found. The same thing may be also easily performed by trigonometry, when the two places lie under different meridians. For if we measure the distance that separates





parates any two objects, and take the angles which each of them make with a third, the triangle formed by the three objects will be entirely known; so that the other two sides may be as accurately determined by calculation, as though they had been actually measured in the same manner as the first. And by making either of these sides the base of a new triangle, the distances of other objects may be found by trigonometry as before; and thus, by a series of triangles, connected together at their bases, we might measure the whole circumference of the earth. But this is an enterprize as useless as it is laborious: we know the relation which any part of a circle bears to the entire circumference, and, consequently, the measure of a few degrees, or even of one single degree, will be sufficient to give the measure of the whole.

But all the measures that had been hitherto taken, were subject to many inaccuracies, on account of the little attention that was then paid to the niceties of instrumental observations. The means of precision, which have since been found so necessary to an exact investigation of this delicate subject, were then wanting; and without them, it was impossible for either genius or industry to avoid considerable errors. By applying the telescope to the quadrant, and furnishing it with a micrometer, we are able to direct it with more certainty to the object, and

to find the measures of angles with infinitely more exactness, than could have been done by those who were unacquainted with these admirable inventions.

The Academy of Sciences at Paris were the first who perceived the necessity of a new measure of the earth; and they pursued their deliberations with an attention proportionate to the importance of the enterprize. All the states of Europe were now enjoying the blessings of a profound peace; and in this interval of happiness and repose, when the voice of genius could be heard, and the talents of individuals united, and directed to one object, the Academy, with a zeal not always to be found in large bodies of men, were unanimously disposed to encourage and assist in the undertaking. This was a moment favourable to the sciences; both the king and his ministers were men of liberal and enlarged minds; improvements were constantly made in every branch of useful knowledge, and genius had something more than empty praise, as a reward for its labour.

Pl. X.
fig. 3.

Monfieur Picard was the person employed to perform this important business. He began by measuring the distance between Villejuif and Juvify; and this base, which he found to be five thousand six hundred and sixty-three toises, was the one to which he referred all his calculations. He next placed himself at Juvify, and
by

by directing the telescopic sights of his quadrant, the one to the wind-mill at Villejuif, and the other to the spire of the church at Brie, he measured the angle contained by these two directions. Leaving his present station, he removed himself to Villejuif, and by measuring the angle between Juvisy and Brie, he found, by calculation, the distance between Villejuif and Brie to be eleven thousand and twelve toises. This distance he made a new base; and by forming a second triangle between Brie, Villejuif, and Monthleri, he found the distance, in like manner, between Brie and Monthleri, to be thirteen thousand, one hundred and twenty-one toises. He then formed a third triangle between Monthleri, Brie and Monjay; a fourth between Monthleri, Brie and Malvoisine; and a fifth between Monthleri, Monjay and Mareil; and from all these measures, he found the distance between Mareil and Malvoisine to be thirty-one thousand, eight hundred and ninety-seven toises. And, in like manner, by means of thirteen triangles, he proceeded as far as Sourdon, near Amiens. and found the distance between Sourdon and Malvoisine to be sixty-eight thousand, four hundred and thirty toises.

But as calculations are no less subject to errors than mechanical operations, Picard, in order to avoid every inaccuracy of this kind, took a

new base near Sourdon, and found its length, both from a continuation of his trigonometrical operation, and from an actual mensuration of it; and as these exactly agreed, he could no longer doubt the truth of his former calculations. I shall not mention all the precautions that were taken in measuring these two bases; separated by so large a distance, it was impossible for them to correspond, but by a perfect exactitude in all the intermediate steps. An error committed in the length of the first base, must have been considerably augmented by such a long series of triangles; all the distances which were found from calculation, must have been subject to this error; and any one of them being measured, near the end of the operations, the error must have become very sensible; and the lengths found by calculation and measurement must have been different.

Pl. X.
fig. 4.

This part of his project being finished, he had now got to reduce the distance between Sourdon and Malvoisine to an arc of the meridian. For this purpose, he placed himself at the observatory at Paris, and found the angle which the sun's center made with an object in the horizon, at the time of his setting; for instance, with the spire of the church at Montlheri. And as this angle was known from observation, and the sun's motion being sufficiently understood for him to find the angle which its center made with the
meridian

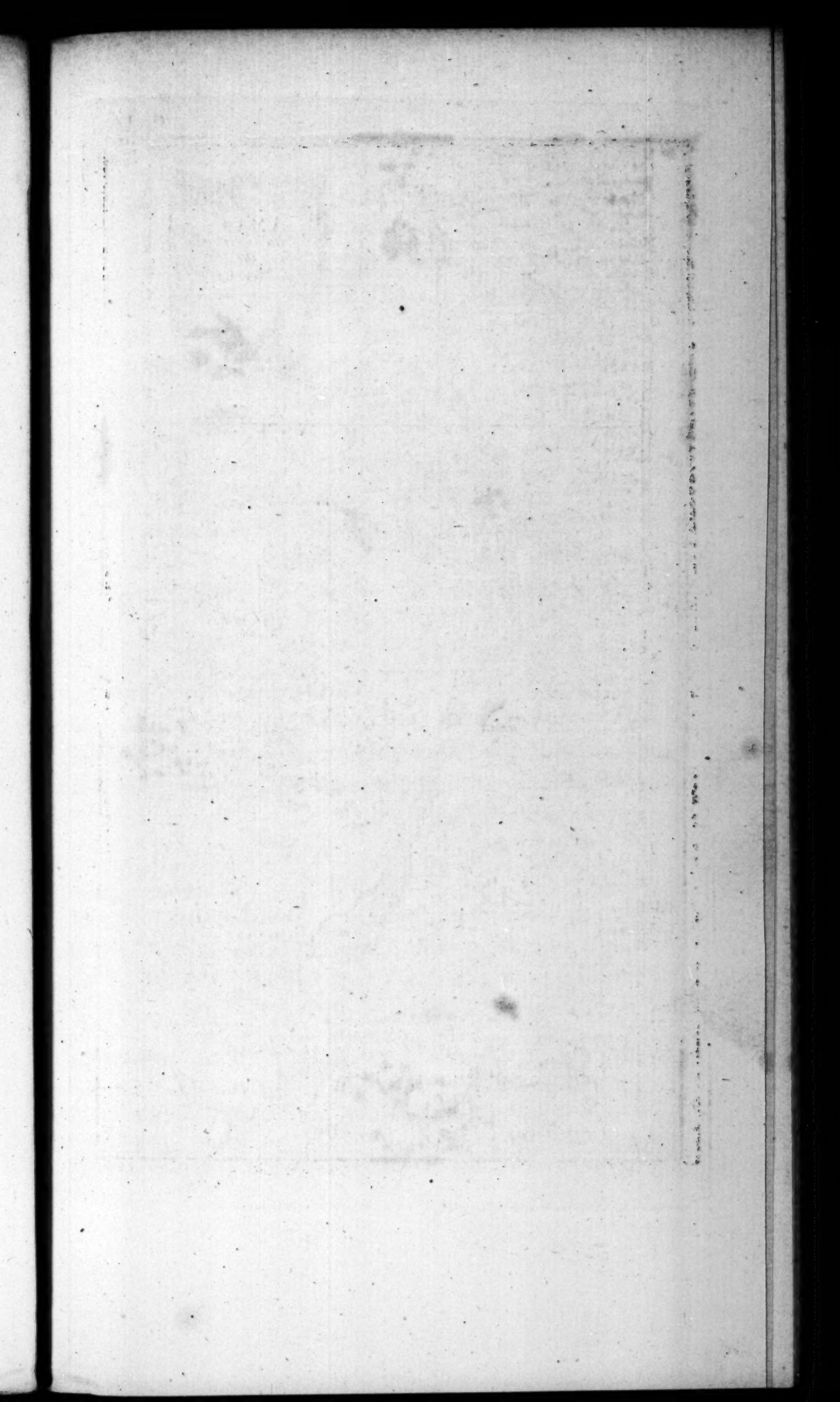
meridian at the time of its setting, it was easy to find the angle which the spire of Montlheri makes with the meridian that passes by the Observatory of Paris. And by a frequent repetition of these observations, as he followed the chain of his triangles, he assured himself of the direction of the meridian; and by that means, was enabled to draw it with more exactness in the chart which contained his operations.

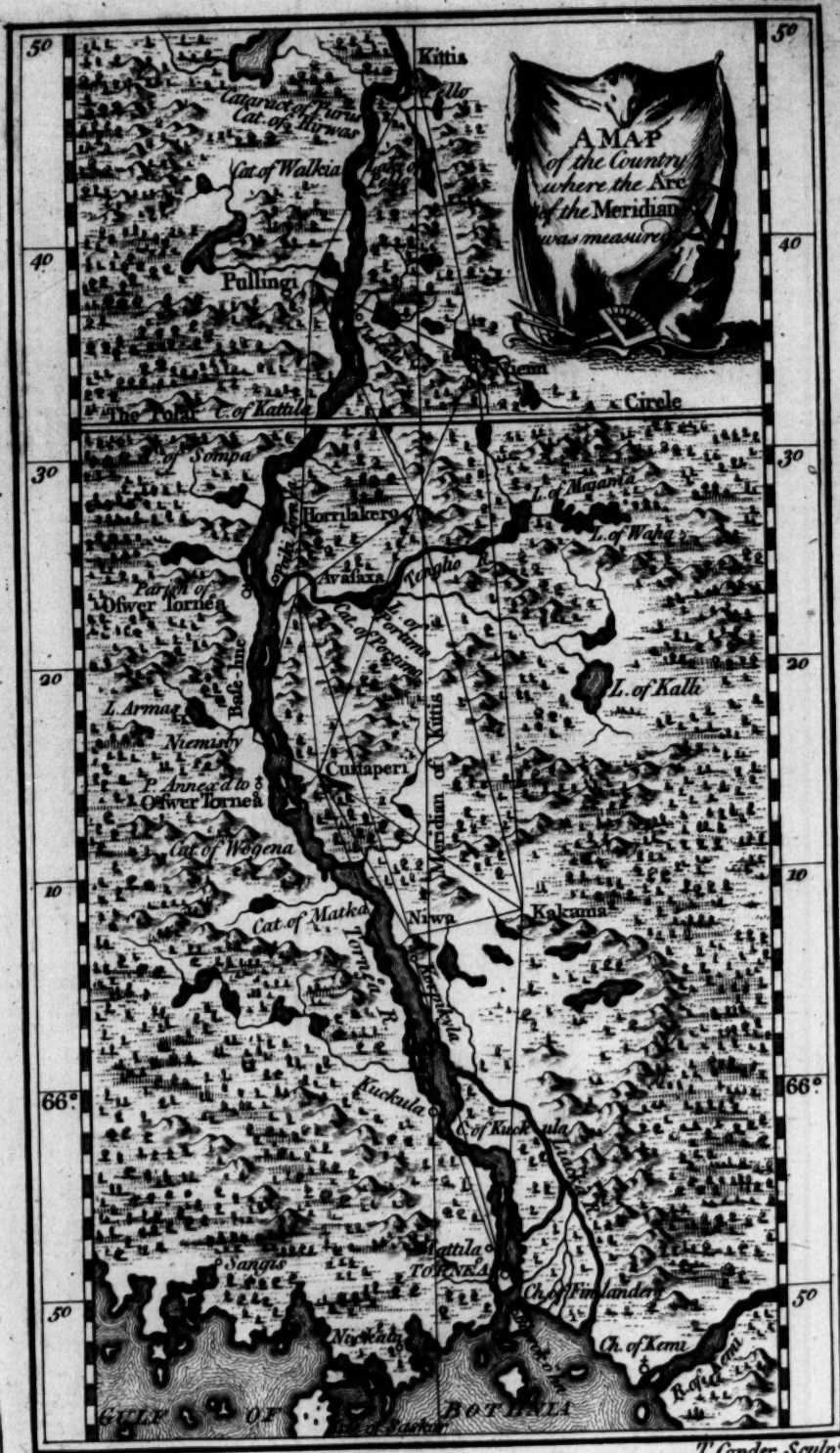
Having obtained this terrestrial distance to so great a degree of accuracy, he had nothing more to do than to find the celestial arc which corresponded with it. This he did by observing the meridian distances of the same star, both from the zenith of Sourdon and Malvoisine, and taking their difference. And as this difference, which he found to be one degree, eleven minutes and fifty-seven seconds, answered to a distance of sixty-eight thousand, four hundred and thirty toises upon the earth, he concluded, by the rule of proportion, that the length of a degree must be fifty-seven thousand, sixty-four and a half toises. But having connected Amiens to his series of triangles, and finding from this new measure, that a degree would be fifty-seven thousand and fifty-seven toises, he took a mean between the two, and fixed his degree at fifty-seven thousand and sixty toises, or about sixty-nine and a half English miles. All the angles were taken with a quadrant of thirty-eight

inches radius, properly furnished with telescopic sights, and the zenith distances of the stars, with a sextant of ten feet radius; so that with these instruments, and the known exactness of the observer, but little doubt could be entertained of the accuracy of his measures.

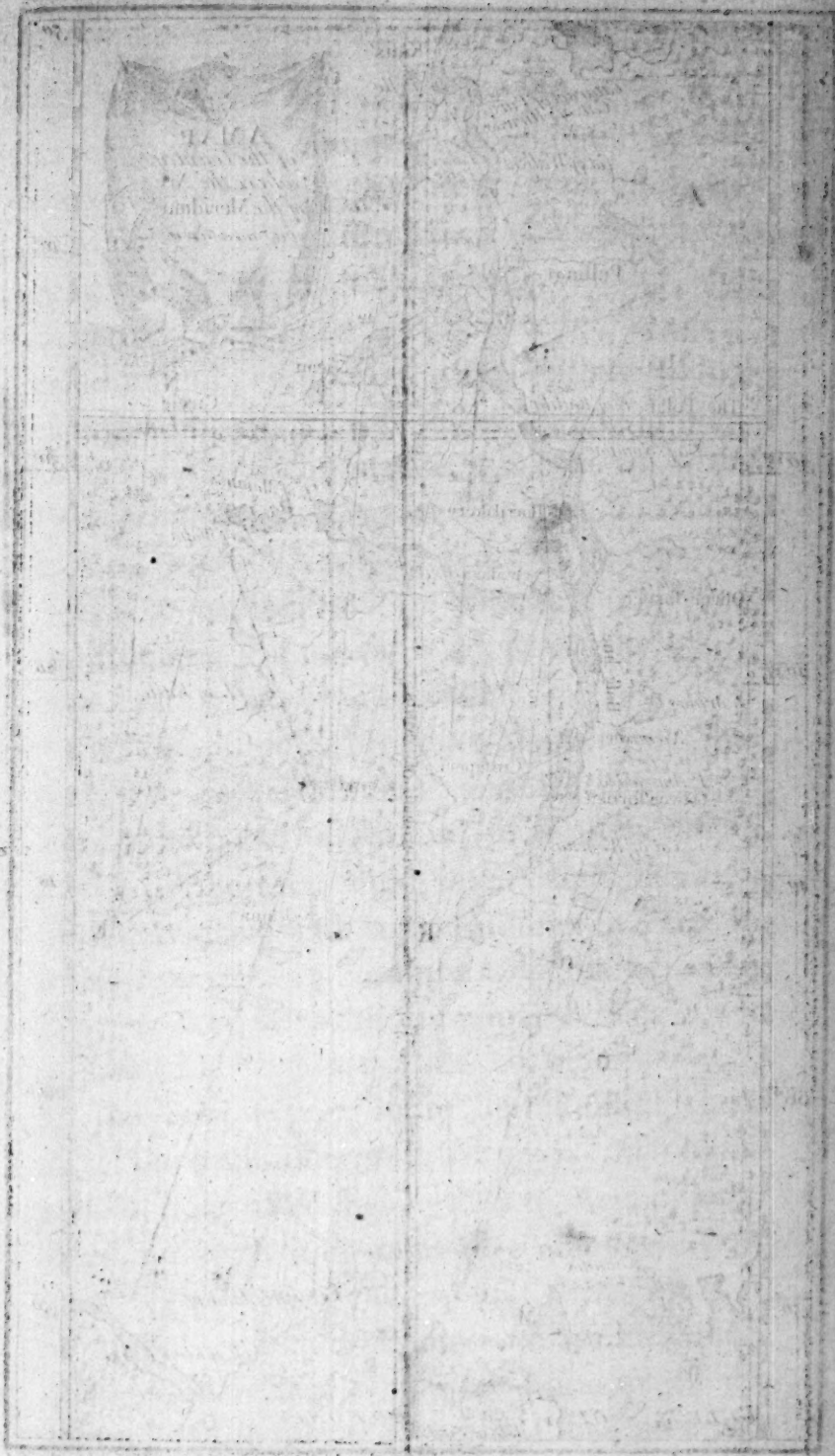
But in order that this subject might be settled with the utmost precision possible, it was determined by the French king, that the whole arc of the meridian, passing through France, should be measured in the same manner; and this great work, which was undertaken by Picard, de la Hire and Cassini, was finished by the latter in the year 1718. He divided the meridian of France into two arcs, which were measured separately; the one from Paris to Collioure, had given him fifty-seven thousand and ninety-seven toises to a degree; the other from Paris to Dunkirk, fifty-six thousand nine hundred and sixty; and the whole arc, from Dunkirk to Collioure, fifty-seven thousand and sixty; which was the same as had been before determined by Mr. Picard.

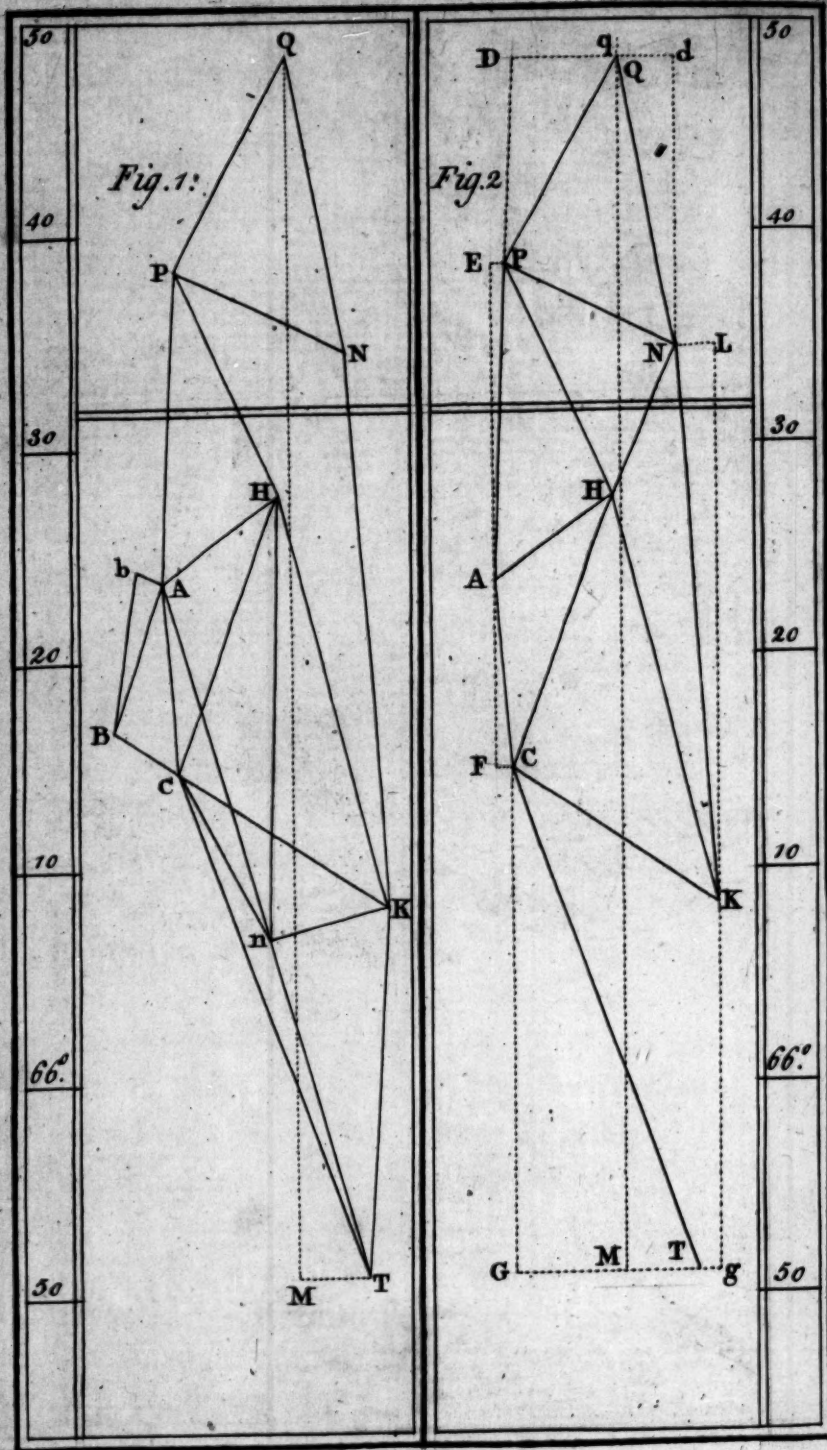
These surveys were all undertaken upon a supposition that the earth was a perfect sphere; but the truth of this doctrine began now to be much controverted. Newton and Huygens had shewn, from the known laws of gravitation, that the true figure of the earth was that of an oblate





T. Conder Sculp^t.





oblate spheroid, flattened at the poles, and protuberant at the equator. Dominique Cassini, on the other hand, depending more upon the accuracy of his measures, than upon deductions drawn from theoretical reasoning, asserted it to be that of a prolate spheroid, flattened at the equator, and protuberant at the poles. To decide this important question, which had now become a national concern, it was ordered by the French king, that a degree should be measured, both at the equator and polar circle; so that from a comparison of these with that in France, the true figure of the earth might be determined in as exact a manner as possible.

For this purpose, Messieurs Maupertuis, Clairaut, Camus, le Monnier and Outhier, were sent to the north of Europe, to measure the remotest degree they could reach; and Messieurs Godin, Bouger, and la Condamine, to Peru, in South America, to measure a degree near the Equator. The first of these companies began their operations at Tornea, near the Gulph of Bothnia, on the 8th of July, 1736, and finished them about the beginning of June, 1737. Mr. Maupertuis, soon after their return to France, published an exact and interesting account of all their transactions; and as this enterprise was conducted by men of science and abilities, who appear to have used every precaution which the delicacy of the subject required, I shall give you
a short

a short abstract of their proceedings, and refer you, for further particulars, to the work itself.

Plate XI. is a map of the country, where the arc of the meridian was measured; and Plate XII. fig. 1, 2, a series of triangles, reaching from Tornea to Kittis. These being connected together at their basis, by proper signals, they measured with a quadrant of two feet radius, all the angles about the points T, K, *n*, C, B, A, H, N, P and Q, and reduced them to the plane of the horizon. After this the line B *b*, which was made the base of all their operations, was measured twice over, by two several companies; and as this was the longest line that had ever been taken upon such occasions, and lay entirely upon the plane surface of the ice of the river, but little doubt could be made of its having been accurately determined.

The length of this line B *b*, being thus found, by an actual mensuration, and all the angles of the triangle B A *b*, being known from observation, it was easy, by a trigonometrical process, to find the length of the line AB; and by having AB, and the angles of the triangle A B C, the length of the line A C might be found in the same manner. This was accordingly done; and a like operation being carried on through all the triangles A C H, C H K, C K T, A H P, H N P and N P Q, the results gave the lengths of the lines A P, P Q, A C and C T, which were
the

the western boundaries of the survey, from Q to T. And from another series of triangles ACH, CHK, CKT, HKN, HNP and NPQ, which were resolved in the same manner, they determined the eastern boundaries of the survey, QN, NK and KT.

Having found the length of these lines as accurately as possible, the next thing to be done, was to determine the angles which they made with the meridian QM. For this purpose, an instrument was fixed upon the centre of the signal at Kittis; and the time of the sun's passage over the vertical circles that pass through Pullingi and Niemi being very exactly noted, it was easy, from the time, thus found, the latitude of the place, and the sun's declination, to find the bearing of the lines QP and QN, or the angles PQD and NQd. This was done by a proposition in spherical trigonometry; and from similar observations, made at the points P, C, L and K, the angles APE, ACF, CTG, KNL and KTG were determined in the same manner.

In the right-angled triangles DQP, APE, ACF and CTG, there were now given one side in each, and all the angles; and from these data they obtained the parts of the meridian PD, AE, AF and CG, whose sum was equal to the whole arc QM. This was precisely the thing wanted; but as the right-angled triangles

QN d,

Q N d, K N L and K T G had also one side in each, and all their angles given, these were solved in the same manner as before; and the parts N d, K L, and K g, being added together, gave a new measure of the arc Q M; which being added to the former one, and a mean taken between them, it was found that an arc of the meridian contained between the parallels of Tornea and Kittis, was equal to $55023\frac{1}{2}$ toises. And as the amplitude of this arc was found, by means of the zenith distances of certain fixed stars, to be 57 minutes, 28 and $\frac{2}{3}$ seconds, it was determined, after proper corrections, that the true length of a degree of the meridian which cuts the polar circle is 57422 toises.

This is the result of the measures made by the Academicians in the north. Those who were sent to Peru, in South America, had still greater difficulties to encounter than their friends in Lapland, and were a longer time employed in their operations. They set out upon their expedition about a twelvemonth before the former, and did not finish their survey till the year 1741. The province of Quito was the place fixed upon as the properest for their purpose. Here they measured an arc of the meridian of three degrees, seven minutes, and one second, and found it to contain 176950 toises; which being reduced to the level of the sea, and properly corrected, the first degree of the meridian, from the equator,

equator, was found from thence to be equal to 56753 toises.

These measures afford a complete demonstration that the earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a globe, as was formerly imagined, a degree of the meridian, in every latitude, would have been found of the same length; and had the figure been that which was given to it by Cassini, a degree at the polar circle would have been found less than a degree at the equator. But as a degree at the equator appears to be about 307 toises less than a degree in France, and about 669 toises less than a degree at the arctic circle, it is easy to shew, that the figure of the earth must be nearly the same as was assigned by Newton; and from having the length of any two degrees, at a sufficient distance from each other, all its other dimensions may be mathematically determined.

L E T-

L E T T E R XVI.

OF THE DISTANCES AND MAGNITUDES OF THE SUN,
MOON, AND PLANETS.

IT was a question, put by Mr. Molineaux to Mr. Locke, whether a blind man, who had been taught to distinguish a globe from a cube by the touch, would be able, if he could be made to see, to tell which was the globe and which the cube, by the use of his sight only. This question that great man answered in the negative; and in his celebrated *Essay on the Human Understanding*, he has shewn that a person, so circumstanced, could have no dependence whatever upon his newly acquired sense, but would find himself totally unqualified to judge both of the situation and distance of objects, as well as of their magnitude and figure.

A young man, who had been born blind, had the use of his eyes given to him by Mr. Chiselden, an eminent surgeon of that time, and all the ideas of the youth, on whom this extraordinary operation was performed, were in favour of Mr. Locke's opinions. At the age of about fourteen years, he saw the light for the first time in his life; and was so perplexed and embarrassed with every thing about him, that he
scarcely

scarcely knew what to make of his new situation. For a long time, he could form no judgment of things by the use of that sense alone. An object of an inch in diameter, placed before his eyes, that concealed a house from his sight, appeared to him as large as the house. Whatever he saw, seemed to be upon his eyes, and to touch them, as the objects of the sense of feeling touch the skin.

His embarrassments increased: what he had judged to be round, by the help of his hands, he could not distinguish from what he had judged to be square; nor could he discern by his eyes, whether what his hands had perceived to be above or below, was really above or below. It was not till after two months experience, that he could tell pictures from solid bodies: he thought bodies, and not surfaces, were in the painted canvas; and when he applied his hand to them, was amazed to find that they vanished from his touch. He was continually asking which of the senses it was that deceived him, that of feeling, or that of seeing. He could not understand how it was possible for his house to be larger than his chamber, and even after he had acquired the proper use of his eyes, he was utterly at a loss to conceive how sight had given him that idea.

This was an indisputable decision, that the manner in which we see objects, is no immediate consequence of the angles formed in our eyes;

eyes; for the same angles were in the eyes of this youth, as well as in ours, but they were of no use to him without the aid of experience, and the other senses. In what manner then do we represent magnitudes and distances to ourselves? and how do we judge of the figure and situation of objects? Certainly by the joint use of the senses of seeing and feeling together, and not by means of either of them separately employed. Neither the touch, nor the sight, can any more convey an idea of the figure or magnitude of a body to the mind, than the taste can convey an idea of colour.

After having acquired these ideas by experience, the mind has received impressions that remain with her for ever afterwards. Being now enlightened and instructed, she forms a judgment without entering into all the circumstances and deductions that were necessary for her first information; and, like a skilful artist, employs the fewest means to attain the end proposed. Having thoroughly acquainted ourselves with the objects around us, we find connections and relations that enable us to form a judgment of those that are more remote; and by creating to ourselves artificial organs, which supply the defects of the natural ones; we extend our faculties beyond the apparent limits prescribed to them by nature, and subject the sense of feeling to the sense of sight.

Astronomy has enlarged the sphere of our conceptions, and opened to us a universe without bounds, where the human imagination is lost. Surrounded by infinite space, and swallowed up in an immensity of being, man seems but as a drop of water in the ocean, mixed and confounded with the general mass. But from this situation, perplexing as it is, he endeavours to extricate himself, and by looking abroad into nature, employs the powers she has bestowed upon him in investigating her works. He proportions his own duration to that of the world; and representing to himself the insensible flux of time by similar analogies, he forms an idea of that which is not, and of that which may never be, and places before his mind a picture of the past, present, and future state of the world.

These are the fruits of genius and curiosity. To an active and persevering mind apparent impossibilities become probable: where the will and desire are not wanting, we are always able to extend the circle of human activity beyond its ordinary limits. The progress of reason, and the powers of the imagination, are almost without bounds; and if we add to this, the invention of instruments, which are so many new organs of power and perception, man becomes a being worthy of admiration. He increases his strength by the assistance of the elements, augments and multiplies the powers of his senses,

T

assures

affures himself of their truth, and corrects their errors; and by this means creates to himself a new being, and adds to his faculties an extension and exactitude which nature seemed to have denied him.

It should appear, that Astronomy depends altogether upon the sight. This is the most extensive of all our senses: it transports us every where, and enables us to enjoy the entire spectacle of the universe.

“ Takes in, at once, the landscape of the world,

“ At a small inlet, which a grain might close,

“ And half creates the wondrous world we see.”

YOUNG.

But this sense, like all the other, is subject to delusion; and requires frequent correction before it can give us a perfect idea of the situations, magnitudes and distances of bodies. Of those objects that are near to us we may form a conception, by subjecting them to a rigorous examination; but when they are inaccessible, and we have no means of transporting ourselves to them, it should seem that we have arrived to the utmost limits of our knowledge and power. When we look at the heavenly bodies, the sight represents them as very small, and the mind, at the same time, conceives them to be very large; but how do we know that they are in reality large? How is it that the mind contradicts the senses?

senses? And how, in this immense abyſs of ſpace, can we contrive to reconcile them to each other?

Some of the moſt ſimple contrivances have frequently given birth to the grandeſt inventions of art. We touch with a ſtick what we cannot reach with our hands, and this gives us an idea of diſtance and ſolidity, without approaching the object. A rod of wood, or metal, pointed towards the ſun or a ſtar, in like manner, ſhews its direction; and by means of the viſual ray which paſſes along the rod, from the object to the eye, we obtain an idea of its ſituation; and thus aſſure ourſelves of a truth, that the un-aſſiſted ſight could never have acquainted us with.

But this is ſufficient only for determining the direction of a ſingle object; when there are two objects, or only one of a certain extension, it will inform us neither of their diſtance nor magnitude. We muſt now have two rods, or an inſtrument with two branches; and by directing the ſight ſucceſſively along each of theſe rods, their inclination or opening will preſent us with an exact meaſure of their diſtance. But how, you will ſay, can an angle determine the diſtance of objects? This is a new mode of meaſuring, apparently foreign to the purpoſe: lines are meaſured by other lines, of a certain length, ſurfaces by ſquares, and ſolids by cubes, or by their weight; but here the meaſure is an angle.

How is the quantity of this angle to be determined? and when the quantities are different, how are they to be compared together?

These inventions are the produce of genius and penetration, their excellence being hid in the simplicity of the operations. If we represent to ourselves the time when Geometry was in its infancy, when men were not accustomed to consider the properties of figures, we may easily perceive how much they must have been embarrassed with these difficulties, and what talents and industry it required to conquer them. It must have been the work of time; many attempts, and many preliminary inventions, must have been thought of; which would be difficult because they were the first, and sublime because they were simple.

Simplicity is, at present, reckoned the supreme merit of all new inventions; and this is only to be obtained by superior minds; all great discoveries are generally preceded by tedious efforts, and a long complication of circumstances, foreign to the purpose, but ending at last in a simple and happy conclusion which was never expected. If this be the case now arts and sciences have arrived to such a degree of perfection, and when minds are enlightened by a free communication with each other, how must it have been when the arts were in their infancy, and a single solitary genius was combating the prejudices of a
gross

gross multitude, whose ideas were as rude as their manners were barbarous.

In examining our new instrument it may be observed, that as two stars become more distant from each other, we must open the two rods accordingly, and make them recede farther from each other, by a movement of rotation, round that extremity which is common to them both. And by making them move entirely round the center, we find that this revolution is always a certain fixed and invariable measure. Whatever be the distance of the two stars, whether great or small, the opening of the two rods will be always an assignable part of the whole revolution; so that if the two rods be equal, and their extremities be made to move over a circle of wood or metal, the path described by them will immediately become known. And if the circumference of this circle be divided into equal parts or degrees, we can tell what part of the circle the moveable rod has described, and thus every distance becomes measurable.

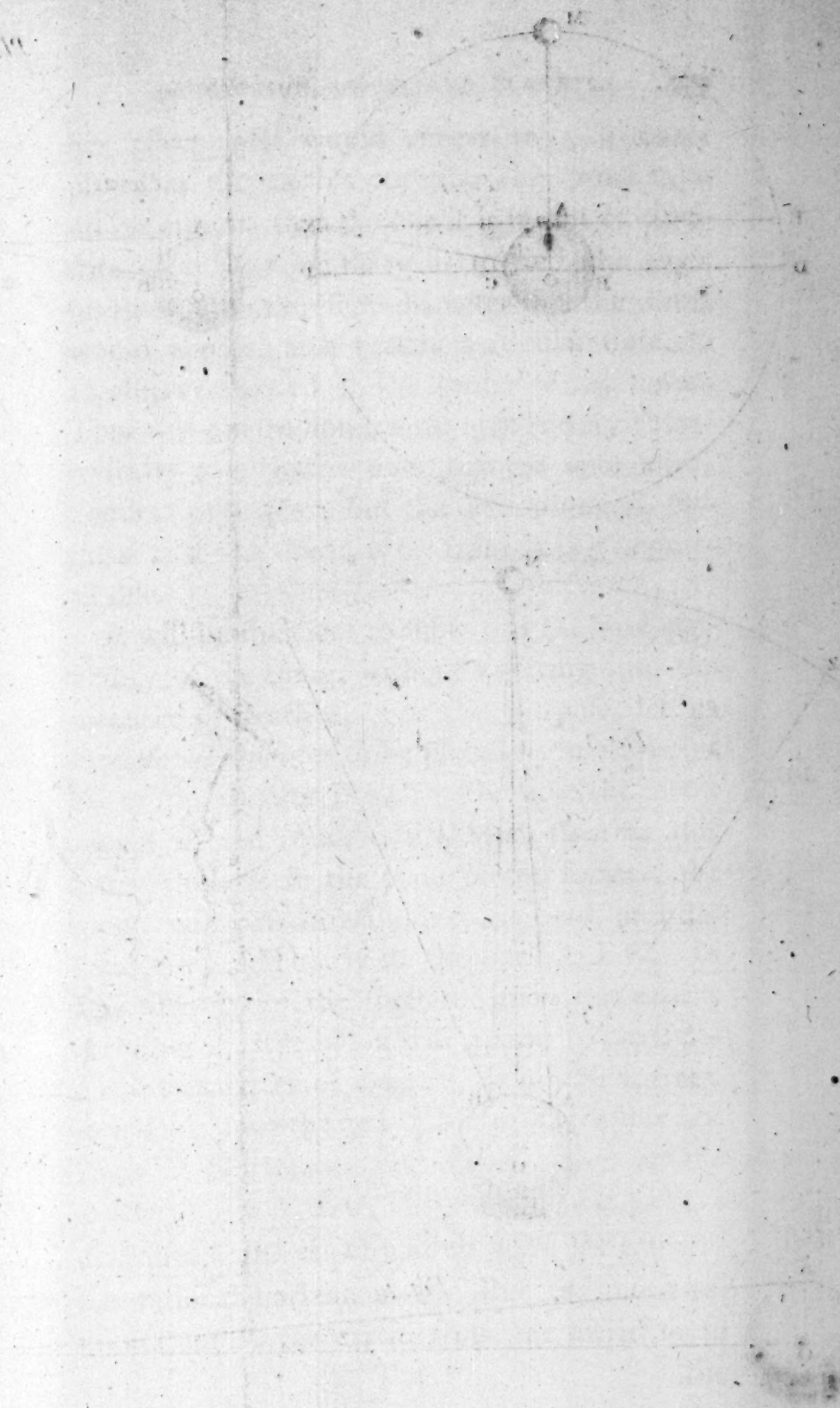
This simple, admirable instrument, and the measuring of celestial distances by means of angles formed by a circular movement, are contrivances of such extensive utility and importance, that they merit our highest encomiums. The authors of these inventions improved the sciences, and extended the circle of human in-

telligence. All that has been done since, has been only to advance a few steps farther in the same path. Our most ingenious and celebrated instruments are little more than this primitive instrument improved. The efforts and success of the moderns cannot be too much praised; but if the labour of ages has enabled us to correct our masters, we ought not to forget that they invented what we have brought so near to perfection.

Astronomy furnishes us with a variety of methods for determining the distances of the celestial bodies; but as many of them are involved in long calculations, which are intelligible only to mathematicians, I shall confine myself to those that admit of the most familiar explanation, and endeavour, by that means, to set the subject in so clear a light, that you can no longer doubt of the possibility of resolving this curious problem. We will first begin with the moon: this planet is nearer to us than any of the rest, and the method of finding her distance from the earth being once known, it will be easy to perceive that the distance of any other planet may be determined in nearly the same way.

The first thing to be done, in the method I am about to describe, is to find the moon's horizontal parallax, or the difference between the place of the moon when she appears in the horizon, to a spectator on the earth's surface, and her

1. 19.



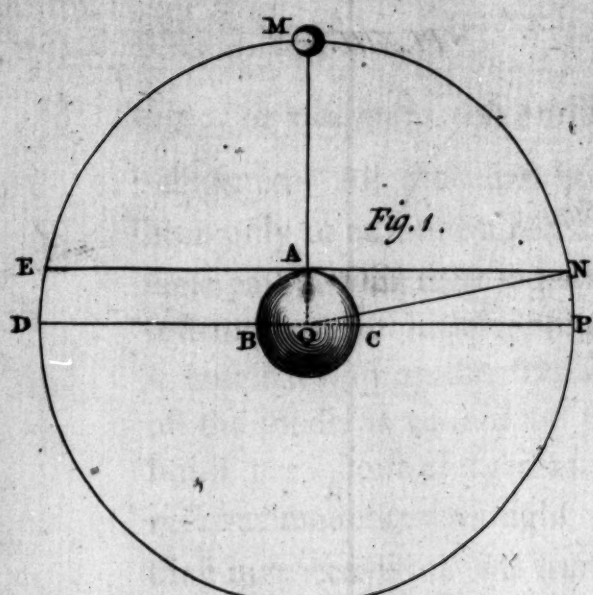


Fig. 1.

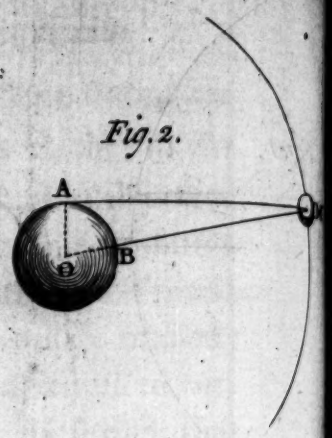


Fig. 2.

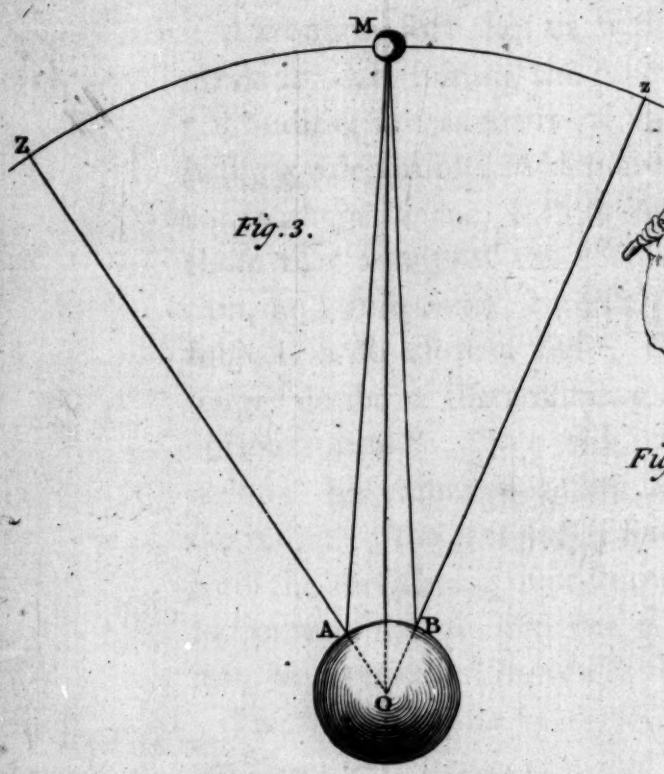
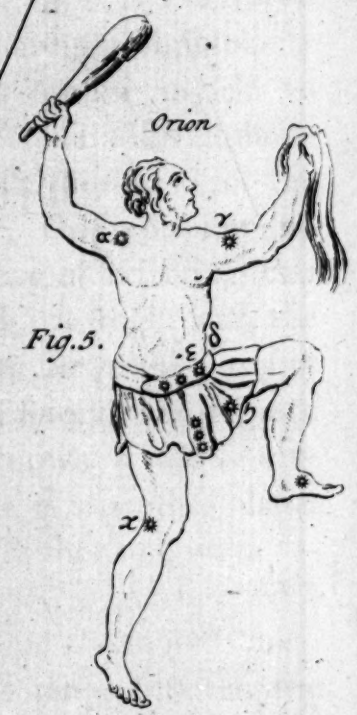


Fig. 3.



Orion

Fig. 5.

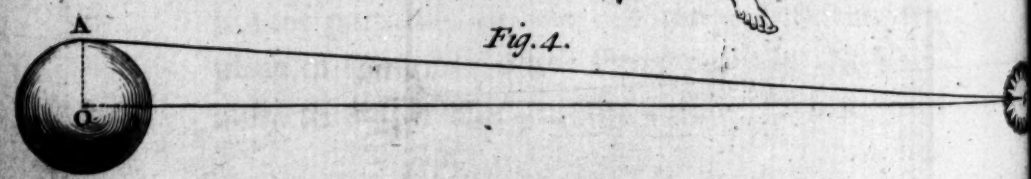


Fig. 4.

her place as it would appear to a spectator placed at the earth's center. This problem is no less curious than the one it is meant to elucidate: it is the same thing as to find the angle under which the semi-diameter of the earth would appear, at a certain particular time, to an observer placed at the center of the moon. That this can be done, must appear very extraordinary to a person unacquainted with astronomical principles; but the determination, singular as it may seem, is far from being impracticable.

It will be sufficient to shew you the bare possibility of the thing, without entering into the minutiae of practice. For this purpose, let us suppose an observer to be placed upon any point A, of the equator B A C, at the time the moon moves in the equinoctial D M P; then as this latter circle is in the plane of the former, the moon will pass directly over his head, and descend perpendicularly to the horizon E N. In this situation of the spectator upon the earth's surface at A, the moon will appear to have described a quarter of a circle, or ninety degrees, in passing from the zenith M to the sensible horizon at N; but to a spectator placed at the center of the earth O, she would appear to have described a quarter of a circle when she came to the rational horizon at P. But the moon revolves round the earth, from the meridian to

Pl. XIII.
fig. 1.

the meridian again, in about twenty-four hours and forty-eight minutes; she will therefore revolve from M to P in six hours and twelve minutes; and if the time she takes in moving from M to N be found by observation, and taken from six hours twelve minutes, the time of moving from M to P, the remainder will be the time employed in describing the arc NP.

Having thus found the measure of the arc NP in time, we can convert it into degrees and minutes, as follows; As the time of describing the arc MN, which is found by observation, is to ninety degrees, so is the time of describing the arc NP, to the degrees and minutes in that arc. But this arc is the measure of the angle NOP, or of its equal ONA; for since the lines AN and OP are parallel to each other, it is a known property of geometry, that the angle NOP will be equal to the angle ONA. This angle ONA is called the moon's horizontal parallax, and as that is now found, we can easily determine the distance of the moon from the earth's center. For it is a maxim in trigonometry, that when any three things in a plane triangle are known, except the three angles, the rest may be found by calculation.

Now, in the triangle AON we have the side OA, equal to half the diameter of the earth, which, from an actual mensuration of the circumference, has been found to be about 3960 miles;

miles; the angle ONA , or the moon's horizontal parallax, has also been found by observation; and the angle OAN is a right angle, because OA is perpendicular to the sensible horizon EN . These three things, therefore, are known, and are sufficient data for determining the rest. The side of the triangle ON is the distance of the moon from the center of the earth O ; and this distance, by a single trigonometrical operation, is found to be at a mean rate about sixty semidiameters of the earth, or, in round numbers, about 240,000 miles.

But the true quantity of the moon's horizontal parallax cannot be accurately determined by this method, on account of the varying declination of the moon, and the inconstancy of the horizontal refractions, which are perpetually changing according to the state the atmosphere is in at the time. For the moon continues but for a short time in the equinoctial, and the refraction, at a mean rate, elevates her apparent place, near the horizon, half as much as her parallax depresses it. Astronomers have, therefore, thought of the following method, which is free from these objections; and if practised by able observers, with good instruments, is sufficient for determining the parallax and distance of the moon to a great degree of precision.

I shall mention the most simple case first, and this will render the general method more clear
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and satisfactory. Suppose two observers were placed under the same meridian at A and B (Pl. XIII. fig. 2.) at such a distance from each other, that the one at A sees the moon M in his horizon, whilst the other at B sees her in his zenith; then will the distance of the moon OM, and the horizontal parallax OMA, be easily determined. For the arc AB, which measures the angle O, is equal to the difference of latitude of the two observers; the side OA is equal to 3960 miles; the same as before; and the angle OAM is a right angle. In the triangle MAO, therefore, there is given a side and two angles, and consequently the side OM, or the distance of the moon from the center of the earth, may be found by trigonometry, as in the former example. And if the angle O be taken from ninety degrees, it will give the angle M, which is the moon's horizontal parallax.

This is the simplest solution the problem admits of; but as it may not be easy to perceive how the two observers can be placed in the manner required, I shall now give you a more general method, by which the distance of the moon from the earth may be determined, when the observers are situated at any two distant places, under the same meridian. Suppose, for example, that the two observers were at the points A and B (Pl. XIII. fig. 3.) whose distance AB, or their difference of latitude, has been previously

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ously found, by the rules already laid down for that purpose; then if the zenith distances of the moon, ZM and zM , be each taken, with a good instrument, at the moment she passes the meridian Zz , the distance of the moon MO from the center of the earth may be determined as follows.

In the triangle ABO , OA and OB are each equal to the radius of the earth, or 3960 miles; and the angle AOB is measured by the arc AB , which is the difference of latitude between the two observers at the time of observation. These three things therefore being known, the side AB , and the angles OAB and OBA , can be found by calculation. And if the angles MAZ and MBz , which are measured by the zenith distances MZ and zM , be each taken from an hundred and eighty degrees, the remainders will be the angles OAM and OBM ; for it is a known property in geometry, that a line standing upon another line, makes with it two angles, which, taken together, are equal to two right angles.

From the angles OAM and OBM , thus determined, take the angles OAB and OBA , which have been found by calculation, and there will remain the angles MAB and MBA ; so that in the triangle ABM , we shall have these two angles, and the side AB , and consequently the side MB may also be found as before. This

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is sufficient for our purpose; we have now, in the triangle OMB , the two sides MB and BO , and the included angle OBM , and therefore the side OM , or the distance of the moon from the center of the earth, may be determined. This might have been done in a shorter way, by first finding the horizontal parallax; but as that method depends upon a theorem in trigonometry, the demonstration of which does not admit of a familiar explanation, I chose rather a more prolix manner, for the sake of its greater perspicuity.

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LETTER XVII.

THE SAME SUBJECT CONTINUED.

THE distance of the sun from the earth might be determined in nearly the same manner as that of the moon's, if his horizontal parallax was not so small as to be scarcely perceptible; for it is well known, that the semidiameter of the earth, as it would appear to a spectator in the sun, can never be subtended under a greater angle than that of nine seconds, or the 400th part of a degree. And as an error of one second, in so small an angle, will occasion an error of about seven million of miles in the distance, it is easy to perceive what an extraordinary degree of skill it must require, to surmount the difficulties attending this delicate subject, when the smallest mistake in the observations will produce an error of so enormous a magnitude.

But the mind grows stronger by frequent exertions, and genius and industry conquer difficulties apparently insurmountable. The vast bulk of the earth has been accurately measured; the stars of heaven have been all numbered; and the immense distance of the sun is now subjected to a rigorous calculation. By means of the transit of
Venus

Pl. XIII.
fig. 4.

Venus over the sun's disk, which happened in the years 1761 and 1769, this problem was resolved with a degree of precision, unlooked for by all the Astronomers of ancient times. The person to whom we are indebted for this excellent method, was the celebrated Dr. Edmund Halley; a man, whose skill and penetration in all mathematical and philosophical enquiries, entitles him to an eminent place in the classes of literature and science. A few extracts from the Dissertation he presented to the Royal Society upon this subject, will shew you the spirit of his method, and enable you to enter into the illustration of it with the greater facility.

“ There are many things, says the Doctor, that appear extremely paradoxical, and seem quite incredible to the illiterate, which yet, by means of mathematical principles, are easily solved. Scarcely any thing will be thought more hard and difficult than that of determining the distance of the sun from the earth; but even this, when we are made acquainted with some exact observations, taken at places fixed upon, and chosen beforehand for that purpose, may, without much labour, be easily effected. And this is what I am now desirous to lay before this illustrious Society, that I may explain to young Astronomers, who may perhaps live to observe these things, the method by which the immense distance of the sun from the earth may be

be truly determined, to within a 500th part of what it really is."

"The distance of the sun from the earth is, by different Astronomers, supposed different, according to what was judged most probable, from the best conjectures they could form. Ptolemy, Copernicus, and Tycho Brahe, imagined it to be about 1200 semi-diameters of the earth. Kepler thought it to be nearly 3500; which distance is doubled by Riccioli, whilst Hevelius only increases it by one half. But Venus and Mercury having, by the assistance of the telescope, been seen to pass over the sun's disc, deprived of their borrowed brightness, it is at length found, that the apparent diameters of the planets are much less than they were formerly supposed; and that the semi-diameter of Venus, as seen from the sun, subtends no more than the fourth part of a minute, or fifteen seconds, whilst the semi-diameter of Mercury is seen, at a mean, under an angle of only ten seconds."

"It has been also found, that the semi-diameter of Saturn, seen from the sun, appears under the same angle as that of Mercury; and that the semi-diameter of Jupiter, the largest of all the planets, subtends an angle of no more than the third part of a minute. Whence some modern Astronomers, imagining that the semi-diameter of the earth, as seen from the sun, would subtend a mean angle, between the larger one

of Jupiter, and the smaller one of Saturn and Mercury, have concluded, that the sun's parallax is about fifteen seconds, or equal to that of Venus, and that his distance from the earth is about 14000 of the earth's semi-diameters."

"But the same authors have somewhat increased this distance on another account; for as the moon's diameter is a little more than one-fourth of the diameter of the earth, if the sun's parallax should be supposed fifteen seconds, it would follow that the body of the moon is larger than that of Mercury; that is, that a secondary planet would be greater than a primary; which should seem to be inconsistent with the uniformity of the mundane system. And, on the contrary, the same regularity and uniformity seems scarcely to admit, that Venus, an inferior planet, that has no satellite, should be greater than the earth, which stands higher in the system, and has such a splendid attendant."

"Let us, therefore, observe a mean, and suppose that the semi-diameter of the earth, as seen from the sun, or, which is the same thing, the sun's horizontal parallax, is twelve seconds and an half; then, according to this supposition, the moon will be less than Mercury, and the earth larger than Venus; and the sun's distance from the earth will be found to be about 16500 of the earth's semi-diameters. This distance I assent to, at present, as the true one, till it

it shall become certain what it is, by the experiment I am about to propose."

"Nor am I induced to alter my opinion by the authority of those, however weighty it may be, who are for placing the sun at an immense distance beyond the bounds here assigned, as the observations made upon the vibrations of a pendulum, in order to determine those exceeding small angles, are not sufficiently accurate to be depended upon; for by this method of investigating the parallax, it will sometimes come out to be nothing, or even negative; that is, the distance will either be infinite, or greater than infinite, which is absurd. And indeed, to confess the truth, it is hardly possible for a person to distinguish seconds with any degree of certainty, by any instruments, however skilfully they may be made; and therefore, it is not at all to be wondered at, that the excessive nicety of this matter should have eluded the many ingenious endeavours of such able operators."

"About forty years ago, when I was in the island of St. Helena, taking a catalogue of the stars near the south pole, I had an opportunity of observing the passage of Mercury over the sun's disc, which, succeeding better than I could have hoped for, I found, with the greatest degree of accuracy, by means of a telescope twenty-four feet long, the very

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moment

moment when Mercury, entering upon the sun, seemed to touch his inward limb; and also, when in going off, it struck the limb of the sun's disc, forming the angle of interior contact; by which means I found the interval of time, during which Mercury appeared upon the sun, even without an error of a single second of time."

"For the lucid line intercepted between the dark limb of the planet and the bright limb of the sun, although exceeding fine, may be seen by the eye, and the little dent made in the sun's limb, by Mercury's entering the disc, appears to vanish in a moment; and also that made by Mercury, when leaving the disc, seems to begin in an instant. When I perceived this, it came immediately into my mind, that the sun's parallax might be accurately determined by such kind of observations as these, provided Mercury were but nearer to the earth, and had a greater parallax from the sun. But the difference of these parallaxes is so little, as always to be less than the solar parallax which we seek; and therefore Mercury, though he may frequently be seen in the sun, is not to be looked upon as fit for our purposes.

"There remains then the transit of Venus over the sun's disc, whose parallax, being almost four times as great as the solar parallax, will cause very sensible differences between the times in which Venus will seem to be passing over the sun at different parts of the earth. And from
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these differences, if they be observed as they ought, the sun's parallax may be determined, even to a small part of a second. Nor are any other instruments required for this purpose, than common telescopes and clocks, which are good of their kind; and in the observers nothing more is requisite than fidelity, diligence, and a moderate skill in Astronomy."

"For there is no need that the latitude of the place should be scrupulously observed, nor that the hours themselves should be accurately determined with respect to the meridian: it is sufficient that the clocks be regulated according to the motion of the heavens, if the times be well reckoned from the total ingress of Venus into the sun's disc, to the beginning of her egress from it; that is, when the dark globe of Venus first begins to touch the bright limb of the sun within; which moments I know, by my own experience, may be observed to within a second of time."

"But on account of the very strict laws by which the motions of the planets are regulated, Venus is seldom seen within the sun's disc; and during the course of 120 years it could never be once observed; namely, from the year 1639 (when this most pleasing sight happened to that excellent youth Horrox, our countryman, and to him only since the creation) to the year 1761; in which year, according to the theories that have

been hitherto found agreeable to the celestial motions, Venus will again pass over the sun, on the 26th of May, in the morning; so that at London, about six o'clock in the morning, we may expect to see her near the middle of the sun's disc, and not above four minutes of a degree south of his center."

"But the duration of this transit will be almost eight hours; namely, from two o'clock in the morning to a little before ten; and therefore the ingress will not be visible in England; but as the sun will at that time be in the 16th degree of Gemini, having nearly twenty-three degrees of north declination, it will be seen without setting in almost every part of the north frigid zone: and therefore the inhabitants of the coast of Norway, beyond the city of Drontheim, as far as the North Cape, will be able to observe Venus entering the sun's disc; and perhaps the ingress of Venus upon the sun, when rising, will be seen by the Scotch in the northern parts of the kingdom, and by the inhabitants of the Shetland Isles, formerly called Thule."

"But at the time when Venus will be nearest the sun's center, the sun will be vertical to the northern shores of the Bay of Bengal, or rather over the kingdom of Pegu, near the mouth of the Ganges; and therefore in the adjacent countries, as the sun, when Venus enters his disc, will be almost four hours towards the east, and as

many towards the west when she leaves it, the apparent motion of Venus over the solar disc will be accelerated by almost double the horizontal parallax of Venus from the sun; because Venus, at that time, is carried with a retrograde motion, from east to west, whilst a spectator, placed upon the earth's surface, is turned the contrary way, from west to east."

"Supposing, therefore, the sun's parallax to be twelve seconds and a half, as I have before conjectured, the parallax of Venus will be forty-three seconds; from which subtracting the former, there will remain thirty seconds and an half, for the horizontal parallax of Venus from the sun: and therefore the motion of Venus will be increased forty-five seconds at least by that parallax, whilst she passes over the sun's disc, at those places which are near the tropic, and yet more in the neighbourhood of the equator."

"Now Venus, at that time, will move on the sun's disc, very nearly at the rate of four minutes of a degree in an hour, and therefore eleven minutes of time, at least, are to be allowed for forty-five seconds, or three quarters of a minute of a degree; and by this space of time the duration of the eclipse, caused by Venus, will, on account of the parallax, be shortened. And from this shortening of the time only, we might safely enough draw a conclusion concerning the

parallax which we are in search of, provided the apparent diameter of the sun, and the latitude of Venus, were accurately known; but in a matter of this subtlety we cannot expect an exact computation."

"We must therefore endeavour to obtain, if possible, another observation, to be taken in those places where Venus will be in the middle of the sun's disc at midnight; that is, in places under the opposite meridian to the former; or about six hours, or ninety degrees west of London; and where Venus enters upon the sun's disc a little before sun-setting, and goes off a little after its rising. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about fifty-six degrees; that is, in a part of Hudson's Bay, near a place called Port Nelson."

"For in this, and the adjacent countries, the parallax of Venus will increase the duration of the transit, by at least six minutes of time; because, whilst the sun, from his setting to his rising, seems to pass under the pole, those places on the earth's surface will be carried with a motion from east to west, contrary to the motion of the Ganges; that is, with a motion conspiring with that of Venus; and therefore Venus will seem to move more slowly on the sun, and to be longer in passing over his disc."

"If

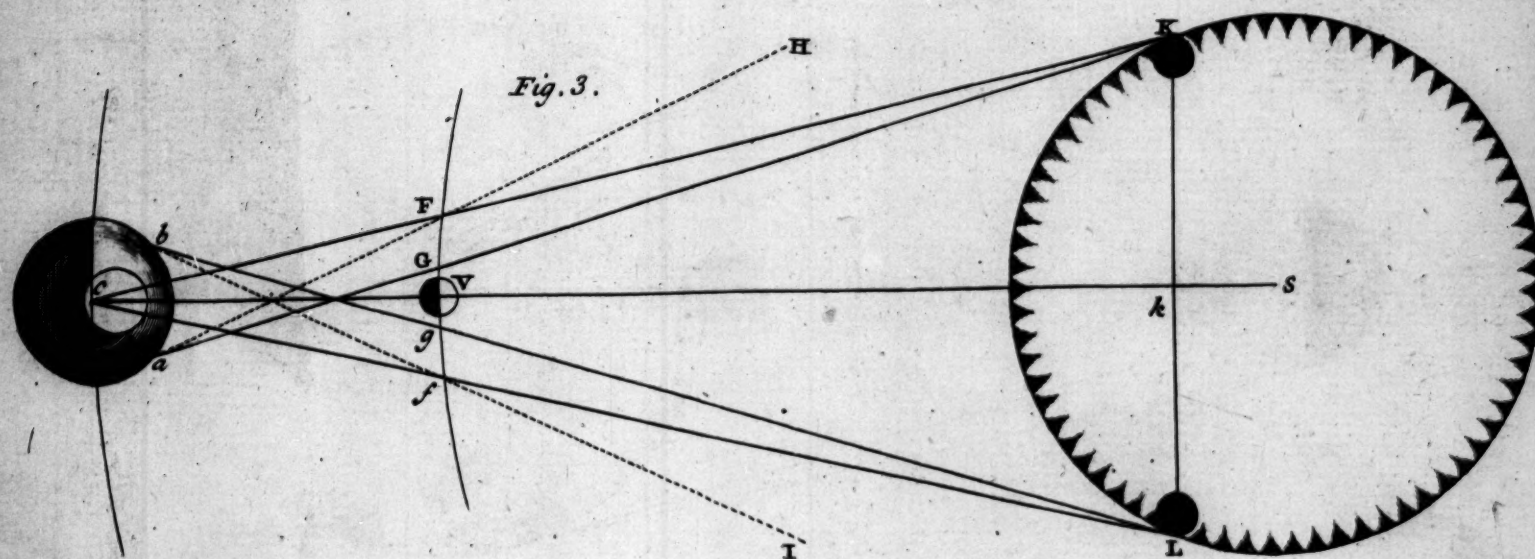
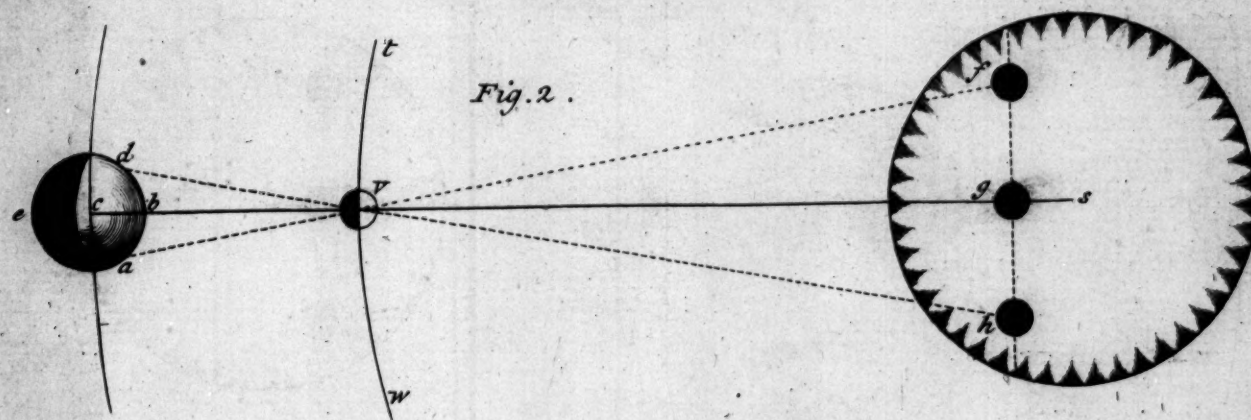
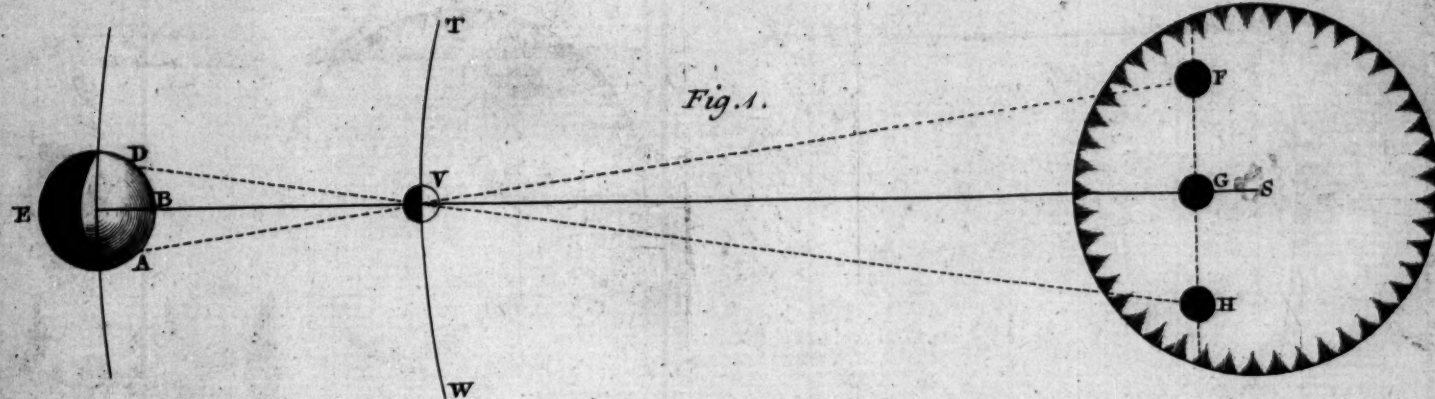
“ If therefore it happen that this transit should be properly observed, by skilful persons, at both these places, it is clear, that the duration of it will be seventeen minutes longer as seen from Port Nelson, than as seen from the East-Indies. Nor is it of much consequence whether the observation be made at Fort George, commonly called Madras, or at Bencoolen, on the western shore of the island of Sumatra, near the equator. But if the French should be disposed to take any pains in this affair, an observer may station himself conveniently enough at Pondicherry, on the western shore of the Bay of Bengal, where the altitude of the pole is about twelve degrees.”

“ As to the Dutch, their celebrated mart at Batavia will afford them a place of observation fit enough for this purpose, provided they also have a disposition to assist in advancing the knowledge of the heavens in this particular. And, indeed, I could wish that many observations of the same phænomenon might be taken, by different persons, at several places; both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of the clouds, of a sight, which I know not whether any man living will ever see again; and on which depends the certain and ade-

quate solution of a problem the most noble in the sciences."

" I recommend it, therefore, again and again, to those curious Astronomers, who may have an opportunity of observing these things when I am dead, that they would remember these admonitions, and diligently apply themselves with all their might to the making of the necessary observations, in which I earnestly wish them all imaginable success: in the first place, that they may not, by the unseasonable obscurity of a clouded sky, be deprived of this most desirable sight; and then, that having ascertained with more exactness the magnitude of the planetary orbits, it may redound to their immortal fame and glory."

" And thus have I shewn," says the Doctor, " that, by this method, the sun's parallax may be investigated to within its five hundredth part, which will doubtless appear very extraordinary to some. But if an accurate observation be made at each of the places above-mentioned, I have already demonstrated that the durations of the eclipse made by Venus, will differ from each other by seventeen minutes of time; that is, upon a supposition that the sun's parallax is twelve seconds and an half. But if the difference should be found, by observation, to be greater or less, the sun's parallax will be greater or less in nearly the same proportion. And since seventeen minutes of time are answerable to
twelve



twelve seconds and an half of solar parallax, for every second of parallax there will arise a difference of more than eighty seconds of time; so that if we have this difference true to two seconds, it will be certain what the sun's parallax is, to within a fortieth part of one second; and therefore his distance will be determined to within its five hundredth part at least, if the parallax be not found less than we have supposed; for forty times twelve and an half makes five hundred."

The Doctor having pursued his subject thus far, in this popular and easy way, proceeds to illustrate it by a figure; but as he has introduced several things into his calculation which could not be understood by a person unacquainted with mathematical principles, I shall endeavour, by means of a simple unimbarraffed scheme, to give you such an idea of the matter, as will at once convince you of the practicability and certainty of this method. The two last transits were in the years 1761 and 1769, and as there will not be another before the year 1874, when almost all the human race now living will in all probability be dead, it will be unnecessary to trouble you with a long account of the methods made use of for observing these eclipses with accuracy and precision, or to enter into any other particulars, than what are sufficient for our present purpose.

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The diameter of the earth is no more than a point in comparison to the distance of the sun; and therefore if the sun were viewed at the same instant, by two observers, on opposite sides of the earth, his center would appear to both of them to be exactly in the same point of the heavens. But when Venus is between the earth and the sun, as she was at the time of her late transits, her distance from the earth is between three and four times less than that of the sun. And, consequently, if Venus be then viewed by two observers on the earth, who are at a great distance from each other, she will appear to each of them to be on different parts of the sun's surface at the same instant.

Thus let S be the sun, (Pl. XIV. fig. 1.) V Venus, and A B D E the earth; and let one observer be at A, another at B, and a third at D, all looking at Venus at the same moment of absolute time. Then, to the observer at A, Venus will appear upon the sun at F; to the observer at B, she will appear upon the sun at G; and to the observer at D, she will appear upon the sun at H. Or if Venus be supposed to be at rest at V, whilst the observer is carried by the earth's motion on its axis, from A to D, through the arc A B D, it is plain that the planet V will then appear to have moved on the sun from F to H, through the space F G H.

Let

Let us now suppose the earth $a b d e$ (fig. 2.) to be nearer the sun S , than as represented in fig. 1; in which case Venus (v) will be proportionally nearer to the earth; and the arc $a b d$, through which the observer is carried, will bear a greater proportion to the distance of Venus (v) from the earth, in fig. 2. than the same arc ABD bears to the distance of Venus (V) from the earth, in fig. 1. So that if one observer should be placed at a , another at b , and a third at c , the observer at a would see Venus on the sun at f ; the observer at b would see her on the sun at g ; and the observer at d would see her on the sun at h ; all at the same instant of time.

Or if Venus continued at rest at v , whilst the observer at a was carried from a to d , by the earth's motion, Venus, in that time, would appear to him to have moved from f to h , on the sun. But the line $f g h$, in fig. 2, is longer than the line $F G H$ in fig. 1; and therefore the nearer the earth is to the sun, the greater will the space be through which Venus appears to move upon the solar disc, by the observer's real motion along with the earth, in any given time: and the further the earth is from the sun, the less will the space be through which Venus appears to move upon the solar disc, by the observer's real motion, in the same time.

And, consequently, as Venus is really moving in her orbit in the direction $T V W$, (fig. 1.) or
 $t v w$,

t v w, (fig. 2.) whilst the observer is carried by the earth's motion on its axis from *A* to *D*, or from *a* to *d*, it is plain, that she will appear to move sooner over the sun, if the earth's distance be only *b v s*, (fig. 2.) than if it be *B V S*, (fig. 1.) So that the whole duration of her transit over the sun must be shorter, if the earth's distance be only *b v s*, than if it be *B V S*.

This being properly understood, let us now suppose the earth to be transparent, like glass, and that you was placed at the center *C*, (fig. 3.) and kept looking at the sun *S*, during the time in which Venus moves in her orbit from *F* to *f*, through the space *F G V g f*. In this case the earth's motion on its axis could have no effect on your position, because it could not carry you away from the point *C*; and therefore when Venus is at *F*, in her orbit, she would appear to you to be just within the sun's surface, touching his eastern edge at *K*, at her first internal contact with him; and as she moves on from *F* to *f*, in her orbit, she would appear to you to pass over the sun, from *K* to *L*, in the line *K L*, which is called the line of her transit over the sun. And when she is at *f*, in her orbit, she would appear to be just beginning to leave the sun's western edge at *L*, at her last internal contact with him. So that if Venus could be seen from the earth's center *C*, she would
move

move from F to f , in her orbit, in the time she would appear to move from K to L on the sun, or from her first internal contact to her last.

This being the appearance of the transit at the earth's center, let us now suppose, that an observer is placed on the earth's surface at a , and that he is carried from a to b , by the motion of the earth on its axis, in the same time that Venus moves from F to f in her orbit. Then when Venus is at F , she will appear on the sun at K , as seen from the earth's center; but to the observer at a , she will not yet be come to the sun, but if she were then visible, would be seen in the line aFH towards the east, and must move on from F to G in her orbit, before the observer would see her on the sun at K , in the right line aGK . So that her transit will begin as much later to the observer at a , than it does to the observer at C , as she is in moving from F to G in her orbit.

When Venus comes to g in her orbit, the observer will be carried from a to b , by the earth's motion, and then he will see her in the line bgL , just beginning to leave the sun at L ; but she must move on from g to f in her orbit, before she begins to leave the sun at L , as seen from the earth's center C , in the right line CfL ; and then, to the observer at b , she will appear quite clear of the sun to the west, in the line BfI . So that the whole duration of the transit,

from

from K to L on the sun, will be shorter as seen by the observer in motion, from *a* to *b*, than as seen by the supposed observer at rest at the earth's center C. For to the former she will move only from G to *g* in her orbit, during the time she appears to move from K to L on the sun: but to the latter, she must move from F to *f* in her orbit, in the time she appears to pass over the sun from K to L.

And the nearer the earth is to the sun, the greater will the difference of the durations of the transit be, as seen from the earth's surface, and from its center: and the further the earth is from the sun, the less will the difference between the durations of the transit be, as seen from the earth's surface, and from its center. For it is plain, from the first and second figures, that the nearer the earth is to the sun, the nearer also, in proportion, will it be to Venus; and the further it is from the sun, the further also it must be from Venus. So that the space through which the observer is carried by the earth's motion will bear a greater proportion to the distance of Venus from the earth, in the former case than in the latter, and must therefore affect the times of the durations of the transit, as seen from the earth's center, and from its surface, accordingly.

Now as the apparent breadth of the sun is known, and the time of Venus's going round the
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the sun is also known, the time of her appearing to move through a space equal to the sun's breadth is easily calculated, and is the same as would be observed by a person placed at rest at the earth's center. And as it appears, from what has been said, that the difference of the durations of the transit, as seen from the earth's surface, and from its center, is greater or less, according as the sun is nearer to or further from the earth, it will be easy to find what this difference must be at all kinds of distances of the sun from the earth. The observer, therefore, by knowing how much shorter the duration of the transit appears to him upon the earth's surface, than it would have done if he had been at rest at the center, may readily find the distance of the sun from the earth, which was the thing to be determined.

The transits that happened in the years 1761 and 1769, were observed with the greatest accuracy and diligence by some of the most eminent Astronomers in Europe, who were sent out to the most convenient parts of the earth for that purpose; and from their determinations it appears, that the horizontal parallax of the sun is about nine seconds, and his distance from the earth, in round numbers, about ninety-five millions of miles. A distance so prodigious, that a cannon-ball, which is known to move at the rate of about eight miles in a minute, would be
some-

something more than twenty-two years in going from the earth to the sun; and if a spectator could be placed in the sun, and was to look at the semi-diameter of the earth, this line, which is about four thousand miles long, would only appear to him under an angle of nine seconds of a minute! Consider this, and you will find it a subject worthy of your admiration and wonder.

The distance of the sun from the earth being thus found, the distances of all the rest of the planets may be easily determined, by the stated laws of nature. For it was discovered by Kepler, from observation, that the squares of the periodic times, in which the planets perform their revolutions round the sun, are in proportion to each other as the cubes of their distances; so that the distance of any one of them being known, the distance of any other may be found by this proportion. Suppose, for example, that I wanted to know the distance of Saturn from the sun, which is the most remote planet in our system; this will be performed by the rule of proportion as follows. As the square of the time in which the earth performs her revolution round the sun, is to the square of the time in which Saturn performs his revolution round the sun, so is the cube of the earth's distance from the sun, to the cube of the distance of Saturn; and if the cube root of this last number be taken,

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it will give the distance of Saturn from the sun, as was required.

And in a manner, equally easy, may the real diameters and bulks of the planets be determined, from their apparent diameters and distances being known. The sun and moon, for instance, appear nearly of the same magnitude; and therefore, if the sun's distance from the earth be reckoned at ninety-five millions of miles, his solid bulk, in order that he may appear as big as the moon, whose distance does not exceed 240,000 miles, must be sixty-four millions of times as big as that of the moon's. Again, The earth's diameter, as seen from the sun at the time of his mean distance, subtends an angle of double the sun's horizontal parallax, which is now supposed to be about nine seconds; and the sun's diameter, as seen from the earth, at that time, is found to be about thirty-two minutes; and therefore the sun's diameter is to the earth's diameter as 1920 to 18. And since the bulks of spherical bodies are to each other as the cubes of their diameters, the sun's bulk will be to that of the earth's as 7077888000 to 5832, or something more than a million of times larger. And, in the same manner, may the diameters and bulks of the rest of the planets be readily determined.

LETTER XVIII.

OF THE MOTION, REFRACTION, AND ABERRATION
OF LIGHT

HAVING measured the globe of the earth, and determined the distances of the sun, moon, and planets, let us now consider the phænomena of light; a subject of no less importance than the former, and equally deserving your attention. It is in this branch of philosophy that the genius of Newton shines with uncommon lustre; and were I allowed to follow him through all his optical experiments and enquiries, I could present you with some of the most astonishing instances of human sagacity that the history of man affords. But as the nature of my plan admits not of such extensive digressions, I shall confine myself to those discoveries which are connected with astronomical observations, and leave the rest for your future consideration.

Various are the opinions that have been entertained concerning the nature of light. The Greeks considered it as an accident, or property, resulting from the first principles of things; and Des Cartes defines it to be a globulous matter,
diffused

diffused through the universe; which being impelled by the sun, strikes upon our eyes, in the same manner as a staff that is pushed at one end presses in the same instant at the other. Moses makes light to have been the first of created things; and Milton, in one of the noblest invocations that poetry can boast, thus expresses the same sentiment.

“ Hail holy light, offspring of heav’n first-born,
Or of th’ eternal co-eternal beam
May I express thee unblam’d? since God is light
And never but in unapproach’d light
Dwelt from eternity, dwelt then in thee,
Bright effluence of bright essence increate.
Or hear’st thou rather pure ethereal stream,
Whose fountain who shall tell? before the sun,
Before the heav’ns thou wert, and at the voice
Of God, as with a mantle didst invest
The rising world of waters dark and deep,
Won from the void and formless infinite.”

The sacred author places the formation of light four days before that of the sun; and in this he appears to have been followed by all the philosophers of antiquity. It was, in those times, the general opinion, that the sun was not the source of light, but that he served to impel and spread it through space.

“ Of all celestial bodies first the sun
A mighty sphere he fram’d, unlightsome first,
Though of ethereal mould: then form’d the moon

Globose, and every magnitude of stars,
 And sow'd with stars the heav'n thick as a field.
 First in his east the glorious lamp was seen,
 Regent of day, and all th' horizon round
 Invested with bright rays, jocund to run
 His longitude through heav'n's high road; the gray
 Dawn, and the Pleiades before him danc'd
 Shedding sweet influence."

MILTON.

This is the language of poetry; but it is now demonstrated that light flows from the sun; and we know exactly the velocity with which it moves. Mr. Roemer, a Danish philosopher, was the first who showed, that it is about eight minutes in its passage from the sun to the earth; and as this singular doctrine will naturally excite your attention, I shall give you his explication of it in as easy a way as possible. The idea was first suggested to him by observing the eclipses of Jupiter's moons, and the conclusion was deduced as follows.

Pl. IV.
 fig. 13.

Let A and B be the earth in two different points of its orbit, whose distance from each other is equal to the earth's distance from the sun S; it is then plain, that if the motion of light were instantaneous, the satellite I would appear, to a spectator at A, to enter into Jupiter's shadow SS, at the same moment of time, as to another spectator in B. But from a great number of observations it was found, that when the

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earth

earth was at B, the emerſion of the ſatellite into the ſhadow happened ſooner, by about eight minutes, than when the earth was at A, and therefore the motion of light muſt be progrefſive, or ſuch as would carry it through a ſpace equal to the radius of the earth's annual orbit in about eight minutes of time. So that if the ſun were annihilated, we ſhould ſee him for eight minutes afterwards; and if he were again created, it would be eight minutes before we ſhould ſee him.

The ſame thing may alſo be ſhewn thus: The inſtant when any of theſe eclipses will happen can be eaſily determined by calculation, becauſe the times, in which they perform their revolutions, are known; and as it is conſtantly found, by obſervation, that any one of the ſatellites is eclipsed about ſixteen minutes ſooner when the earth is neareſt to Jupiter, than when it is fartheſt from him, it is evident, that this muſt be occaſioned by the time that light takes in moving through the diameter of the earth's orbit; for that theſe accelerations are not owing to any inequalities in the motions of the ſatellites themſelves, is plain, becauſe they are always affected alike, in whatever parts of their orbits they are eclipsed.

This explication furniſhes us with the ſolution of one of the moſt curious problems that ever was attempted; which is that of determin-

ing the velocity of light. The minuteſt particles which are thrown off from the body of the ſun, move through a ſpace of ninety-five millions of miles in eight minutes; which is about a million of times ſwifter than the motion of a cannon-ball, when it is firſt projected from the mouth of the piece; a rapidity too great for the imagination to follow, or the mind to comprehend. And yet, prodigious as ſuch a motion appears, there may be ſtars, whoſe light has not reached us ſince the creation of the world. This is the univerſe of the poet;

—————“ Without bound,
Without dimenſion, where length, breadth, and height,
And time and place are loſt.”

The quantity of light and heat which the planets receive from the ſun, decreases in proportion to the ſquares of their diſtances from the ſun; and when a ray of light paſſes out of one medium into another, it is refracted or turned out of its firſt courſe, according as it falls more or leſs obliquely on the refracting ſurface which divides the two mediums. The firſt of theſe propoſitions will appear evident, from the conſideration of a cone of rays, flowing from any luminous point, the circular ſections of which will be always proportional to the ſquares of their diſtances from the vertex; and the latter may be exemplified as follows: Put a ſhilling
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in an empty basin, and retire to such a distance, that the edge of the basin shall just hide it from your sight; then, keeping yourself steady, let another person fill the vessel gently with water; and as the water rises towards the top, the object will become more and more visible, till at length the whole of it will be distinctly seen, appearing as if it had been raised above the bottom of the basin.

This proves that the rays of light are refracted, or bent downwards, in their passage out of the water into the air; and as they now come to the eye in a more oblique direction, the object must necessarily appear to be elevated, and in a different situation from that in which it was really placed. The same thing may also be shown thus: Place the basin in such a manner that the sun may shine obliquely on it, and observe where the shadow of the rim falls upon the bottom; then fill it with water, and the shadow will not extend so far as it did when the vessel was empty; which shows that the rays have changed their direction, by passing out of one medium into another of a different density.

The less obliquely the rays fall, the less they will be refracted; and if they fall perpendicularly, they will not be refracted at all. For, in the last experiment, the higher the sun rises, the less will be the difference between the places where the edge of the shadow falls, in the empty

and full basin. And if a stick be laid across the basin, and the sun's rays be reflected perpendicularly into it from a looking-glass, the shadow of the stick will fall upon the same part of the bottom, whether the basin be full or empty. The same effects will also take place when the experiment is performed with any other fluid: but the denser the medium, the more will light be refracted in passing through it.

From these observations it will readily appear, that objects can seldom be seen in their true places. We are deceived by every thing around us: the sight is no less subject to error than the rest of our senses: they all contribute to our pleasure, and promote our happiness by various means. In consequence of this property of refraction, we enjoy the light of the sun whilst he is yet below the horizon; this being the cause that produces the crepusculum, or the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is in those brilliant colours that paint the clouds, before the rising of the sun, that the poets have placed Aurora, or the goddess of the morn: she opens the gates of day with her rosy fingers; and the daughter of the air and the sun has her throne in the atmosphere.

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Had no such atmosphere existed, the rays of light would have come to us in straight lines, and the appearance and disappearance of the sun would have been instantaneous; we should have had a sudden transition from the brightest sunshine to the most profound darkness, and from thick darkness to a blaze of light. Refraction, therefore, is extremely useful, not only as it prepares us gradually for the light of the sun, but also as it occasions twilight, and by that means prolongs the duration of the day. Nature has established these gradations, to heighten our pleasures by variety; the scene is perpetually changing, but the order of things is immutable and eternal.

“ Look nature through, ’tis revolution all,
All change, no death: day follows night; and night
The dying day; stars rise, and set, and rise;
Earth takes th’ example: see the Summer gay,
With her green chaplet, and ambrosial flow’rs,
Droops into pallid Autumn; Winter gray,
Horrid with frost, and turbulent with storm,
Blows Autumn and his golden fruits away,
Then melts into the Spring; soft Spring, with breath
Favonian, from warm chambers of the south,
Recalls the first: All, to reffourish, fades;
As in a wheel, all sinks, to re-ascend.”

YOUNG.

The refractive power of the atmosphere appears to have been known to Astronomers before the time of Ptolemy; but the first who determined

terminated its effect, and employed it in correcting astronomical observations, was Tycho Brahe. He found, that the horizontal refraction was about thirty-three minutes, which is nearly the same as it is estimated at present; and by means of an instrument, contrived for that purpose, attempted to ascertain the quantity of it at different altitudes. But though Tycho had discovered the effect, he was not so happy in explaining the cause of this phænomenon. He attributed it to the gross vapours that float in the atmosphere, and imagined the refraction of the sun to be different from that of the stars; the former he supposed to extend no further than to forty-five degrees of altitude, and the latter only to twenty. But Dominique Cassini shewed the fallacy of this doctrine, by calculating the refractions for every degree of altitude, and proving that they diminish from the horizon to the zenith.

Pl. X.
Fig. 3.

This determination is agreeable to modern discoveries; but in order that the subject may appear in its true light, I shall elucidate it by a figure. For this purpose, let T represent the earth, surrounded with its atmosphere A E D; S the sun, or a star; and O the place of the spectator upon the earth's surface. Then it is evident, that a ray of light S A, falling upon the gross body of the air at A, will be refracted, or bent towards the line Q P, which is perpendicular

cular to the surface of the atmosphere at that point; and because it is known from experience, that the air is denser in the lower regions of the atmosphere, than in the higher, the same ray will be refracted, not only at A, but at many other points in the medium, before it reaches the spectator at O. But as it is only the last part of the ray C O that affects the sight, the eye will naturally refer the object to s , in the straight line O C s , and will therefore see it in a situation much higher above the horizon than it really is.

And the higher the sun rises, the less will his rays be refracted, because they fall less obliquely on the surface of the atmosphere. Thus, when the sun is in the zenith, his rays will fall perpendicularly upon the atmosphere at B, and continue their course in the right line S B O. But when the sun is below the horizon R H, his rays, falling upon the atmosphere at F, will be bent downwards towards the observer at O; and he will now see the sun in the direction of the refracted ray O a s , which lies above the horizon, and being extended to the heavens, shows the sun in the point s . When the ray S F is a tangent to the surface of the atmosphere at F, it is then the beginning, or end of twilight, according as the sun is rising or setting: and as this is known to take place when the sun is about eighteen degrees below the horizon, it has been
found

found from thence, by a trigonometrical process, that the height of the atmosphere is about forty-five miles. But this must only be understood of that part of the medium which is sufficiently dense to refract the sun's rays; for it is easy to prove, from mathematical considerations, that the atmosphere can have no assignable limits.

It must also be observed, that the state of the atmosphere is exceedingly variable, and that the quantity of refraction is not always the same at the same altitude; for as heat diminishes the density of the air, and cold increases it, the refraction must alter accordingly; and therefore no rule can be given by which we can precisely ascertain, either the height of that part of the atmosphere which refracts the sun's rays, or the true place of any of the celestial bodies which are observed through this medium. And it is not from refraction only that we are unable to find the true places of those objects; they are also subject to other irregularities, which arise from their parallax, and the motion of light. The former of these I have already explained, and I shall now give you some account of the latter. It is a discovery of the celebrated Dr. James Bradley; and as the subject is exceedingly curious and important, I shall present you with the history of it in nearly his own words.

Dr.

Dr. Bradley, in conjunction with the Honourable Samuel Molineux, Esq; in the year 1725, formed a project of verifying, by a series of new observations, those which Dr. Hook had communicated to the public about fifty years before. And as his attempt was what principally gave rise to this, so his method in making the observations was in some measure that which they followed; for they made choice of the same star, and their instrument was constructed upon almost the same principles. But if it had not greatly exceeded the Doctor's in exactness, they might yet have remained in great uncertainty as to the parallax of the fixt stars. Their success, indeed, was chiefly owing to the ingenious Mr. George Graham, F. R. S. to whom the lovers of astronomy are also not a little indebted for several other exact and well-contrived instruments.

Mr. Molineux's apparatus was compleated, and fitted for observing, about the end of November 1725; and on the third day of December following, the bright star in the head of Draco, marked γ by Bayer, was for the first time observed, as it passed near the zenith, and its situation carefully taken with the instrument. The like observations were made on the fifth, eleventh, and twelfth days of the same month; and there appearing no material difference in the place of the star, a farther repetition of them, at that season, seemed needless, it being a part of
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the year in which no sensible alteration of parallax, in this star, could be soon expected. It was chiefly curiosity, therefore, which tempted Dr. Bradley, who was then at Kew, where the instrument was fixed, to prepare for observing the same star on December the 17th; when, having adjusted the instrument as usual, he perceived that it now passed a little more southerly, than when it was before observed. Not suspecting any other cause of this appearance, they at first concluded that it was owing to the uncertainty of their observations, and that either this, or the foregoing, were not so exact as they had before supposed; for which reason they proposed to repeat the observation, in order to determine from whence this difference proceeded; and upon doing it, on December the 20th, the Doctor found that the star passed still more southerly than in the former observations.

This sensible alteration the more surprized them, as it was the contrary way from what it would have been, had it proceeded from an annual parallax of the star. But being now well satisfied that it could not be entirely owing to a want of exactness in the observations, and having no conception of any thing else that could cause such an apparent motion as this in the star, they began to think that some alteration in the materials, &c. of the instrument itself might have occasioned it. Under these apprehensions they remained

remained some time; but being at length fully convinced, by repeated trials, of the great exactness of the instrument, and finding, by the gradual increase of the star's distance from the pole, that there must be some regular cause which produced it, they took care to examine nicely, at the time of each observation, how much it was: and about the beginning of March 1726, the star was found to be twenty seconds farther southerly than at the time of the first observation. It now, indeed, seemed to have arrived at its utmost limit southward; because, in several trials made about this time, no sensible difference was observed in its situation. By the middle of April it appeared to be returning back again towards the north; and about the beginning of June it passed at the same distance from the zenith, as it had done in December, when it was first observed.

From the quick alteration of the star's declination about this time, which was near a second in three days, they concluded, that it would now proceed northward, as it before had gone southward; and it happened as was conjectured; for the star continued to move northward till September following, when it again became stationary; being then near twenty seconds more northerly than it was in March. From September the star returned towards the south, till it arrived in December

ember to the same situation it was in at that time twelvemonth, allowing for the difference of declination on account of the precession of the equinox. This was a sufficient proof, that the instrument had not been the cause of this apparent motion of the star, and to find one adequate to such an effect, seemed a difficulty. A nutation of the earth's axis was one of the first things that offered itself on this occasion, but it was soon found to be insufficient; for though it might have accounted for the change of declination in γ Draconis, yet it would not, at the same time, agree with the phenomena in the other stars, particularly in a small one almost opposite in right ascension to γ Draconis, at about the same distance from the north pole of the equator; for though this star seemed to move the same way as a nutation of the earth's axis would have made it, yet as it changed its declination but about half as much as γ Draconis in the same time, (as appeared upon comparing the observations of both made upon the same days, at different seasons of the year,) this plainly proved, that the apparent motion of the star was not occasioned by a real nutation, since, if that had been the cause, the alteration in both stars would have been nearly equal.

The great regularity of the observations left no room to doubt, that there was some regular cause that produced this unexpected motion, which

which did not depend on the uncertainty or variety of the seasons of the year; and upon comparing the observations with each other, it was discovered, that in both the stars before-mentioned, the apparent difference of declination from the maxima, was always nearly proportional to the versed sine of the sun's distance from the equinoctial points. This induced them to think, that the cause, whatever it was, had some relation to the sun's situation with respect to those points. But as they were not able to frame any hypothesis at that time, sufficient to solve all the phænomena, and were yet very desirous of searching a little farther into this matter, Dr. Bradley began to think of erecting an instrument for himself at Wansted; that, having it always at hand, he might, with the more ease and certainty, enquire into the laws of this new motion.

The consideration likewise of being able, by another instrument, to confirm the truth of the observations hitherto made with Mr. Molineux's, was no small inducement to him; but his principal motive was, the opportunity it would afford him of trying in what manner other stars were affected by the same cause, whatever it was. For Mr. Molineux's instrument being originally designed for observing γ Draconis was so contrived, as to be capable of but little alteration in its direction; not above seven or

eight minutes of a degree; and there being few stars within half that distance from the zenith of Kew, bright enough to be well observed, he could not with his instrument thoroughly examine how this cause affected stars differently situated, with respect to the equinoctial and solstitial points of the ecliptic.

These considerations determined him; and by the contrivance and direction of Mr. Graham, his instrument was fitted up August 13, 1727. As he had no convenient place where he could make use of so long a telescope as Mr. Molineux's, he contented himself with one of but little more than half that length, viz. of twelve feet and an half; judging, from the experience which he had already had, that this radius would be long enough to adjust the instrument to a sufficient degree of exactness: and he had no reason afterwards to change his opinion; for by all his trials he was very well satisfied, that when it was carefully rectified, its situation might be securely depended upon to half a second. And as the place where his instrument was hung, in some measure determined its radius, so did it also the length of the limb, on which the divisions for the adjustment were to be made: for the arc could not conveniently be extended farther than to about six degrees and a quarter on each side his zenith. This, indeed, was sufficient, since it gave him

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an opportunity of making choice of several stars, very different both in magnitude and situation; there being more than two hundred inserted in the British catalogue that might be observed with it. It was not necessary, indeed, to have extended the limb so far, but that he was willing to take in Capella, the only star of the first magnitude that came so near his zenith.

His instrument being fixed, he immediately began to observe such stars as he judged most proper to give him some insight into the cause of the motion already mentioned. There were small ones enough, and not less than twelve that he could observe through all the seasons of the year; as they were sufficiently bright to be seen in the day-time, when nearest the sun. He had not been long observing before he perceived, that the notion they had before entertained of the stars being farthest north and south, when the sun was about the equinoxes, was only true of those which were near the solstitial colure. And after he had continued his observations a few months, he discovered what he then apprehended to be a general law observed by all the stars, namely, that each of them became stationary, or was farthest north or south, when it passed over his zenith at six o'clock, either in the morning or evening. He perceived likewise, that whatever situation the stars were in with respect to the cardinal points of the ecliptic,

the apparent motion of all of them tended the same way, when they passed his instrument about the same hour of the day or night; for they all moved southward while they passed in the day, and northward in the night; so that each was farthest north, when it came about six o'clock in the evening, and farthest south, when it came about six in the morning.

He discovered afterwards, however, that the maxima, in most of these stars, did not happen exactly when they passed at those hours; yet, not being able, at that time, to ascertain the exact limits, he endeavoured to find out what proportion the greatest alterations in declination, of different stars, bore to each other; it being very evident, that they did not all change their declination equally. It has been before remarked, from Mr. Molineux's observations, that γ Draconis altered its declination about twice as much as the before-mentioned small star almost opposite to it: but examining the matter more particularly, he found, that the greatest alteration in the declination of those stars, was as the sine of the latitude of each respectively. This made him suspect, that there might be the like proportion between the maxima of other stars; but finding that the observations of some of them would not perfectly correspond with such an hypothesis, and not knowing whether the difference

ference he met with might not be owing to some small errors which had escaped his notice, he deferred any farther examination till he should be furnished with a series of observations made in all parts of the year, which might enable him not only to determine what errors they were liable to, or how far they might safely be depended upon, but also to judge, whether there had been any sensible change in the parts of the instrument itself.

When the year was compleated, he began to examine and compare his observations; and having pretty well satisfied himself as to the general laws of the phænomena, he then endeavoured to find out the cause of them. He was already convinced, that the apparent motion of the stars was not owing to a nutation of the earth's axis. The next thing that offered itself was an alteration in the direction of the plumb-line, with which the instrument was constantly rectified; but this, upon trial, proved insufficient. He then considered what refraction might do; but here also nothing satisfactory occurred. At last, by a singular sagacity, he conjectured, that all the phænomena hitherto mentioned proceeded from the progressive motion of light, and the earth's annual motion in its orbit. For he perceived, that if light was propagated in time, the apparent place of a fixed object

would not be the same when the eye is at rest, as when it is moving in any other direction, than that of the line passing through the eye and the object; and that, when the eye is moving in different directions, the apparent place of the object would be different.

The means by which we arrive at the knowledge of things, are not less wonderful than the things themselves. A lucky accident often brings truths to light, that abstruse speculation would have never discovered. The curiosity of some children at play, produced the telescope; the absurd attempts that have been made to discover the philosopher's stone, have given birth to some of the noblest discoveries in chemistry; and from observations that were designed to determine the parallax of the stars, was obtained a knowledge of their aberration; a circumstance utterly unknown to the astronomers of former ages. Before the time of Roemer, it was the general opinion that the motion of light was instantaneous; or that it was propagated through immense spaces in an instant. But we are now assured, both from observations that have been made on the eclipses of Jupiter's moons, and from the apparent change of place discovered by Dr. Bradley in the fixed stars, that the
motion

motion of light, like that of all other bodies, is progressive; or that the time it employs in its passage, is proportional to the space described.

That the aberration of the stars is occasioned by the motion of light may be shown as follows: Let AB represent a part of the earth's annual orbit, and CB a ray of light, falling from a star perpendicularly upon the line BA : Then if the eye be at rest at B , the object will appear in the direction BA , whether light be propagated in time, or in an instant; but if the eye be moving from A towards B , and light be propagated with a velocity that is to the velocity of the eye, as CB to AB , that particle of it, by which the object will be discerned when the eye comes to B , will be at C when the eye is at A . The star, therefore, will appear in the direction AC ; and as the earth moves through the equal parts of its orbit Aa, ab, bc , &c. the light coming from the star will move through the equal divisions ci, ik, kl , &c. and the star will appear successively in the directions ae, bf, cg , &c. which are parallel to the former AC ; so that when the eye comes to B , the object will be seen in the direction BD .

Pl. X.
fig. 6.

If the line AC be a tube of such a diameter as to admit but one particle of light at a time, it is easy to perceive, that the particle of light at C , by which the object must be seen, when the eye, as it moves along, arrives at B , would pass

through the tube A C, if it were inclined to A B, in the angle A B C, and accompanied the eye in its motion from A to B; and that it could not come to the eye through such a tube, if it had any other inclination to the line B D. And the same thing will follow, if, instead of supposing A C to be such a small tube, we imagine it to be the axis of a larger one; for, from what has been said, it is evident, that a particle of light at C cannot pass along that axis, unless it be inclined to B A, in the angle B A C.

Although, therefore, the true or real place of an object be perpendicular to the line in which the eye is moving, yet the visible place will not be so, for that must be always in the direction of the tube through which the object is seen; and the difference between the true and apparent place will be greater or less, according to the proportion between the velocity of light and that of the eye. If the earth revolves round the sun annually, and the velocity of light be to the velocity of the earth's motion in its orbit as one thousand to one, it may be proved, by a trigonometrical process, that the apparent place of the object, from which the light proceeds, will constantly differ from the true place by about three minutes and an half; so that a star, placed in the pole of the ecliptic, would seem to describe a circle round that pole, the diameter of which would be seven minutes.

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From a number of observations, made by Dr. Bradley upon the same stars for three years, he found, that their apparent places differed from their true places by about twenty seconds; and by this means it is proved, that the velocity of light is about 10,310 times greater than the velocity of the earth in her orbit; but the velocity of the earth is about 58,000 miles an hour, and therefore light will pass from the sun to the earth, or through 95,000,000 miles, in eight minutes and seven seconds; and as this is nearly the same as the time discovered by Roemer, and was deduced from a different phenomenon, which was owing to the same cause, they mutually confirm each other; and the progressive motion of light is now proved in a manner that admits of no objection.

But this is not the only advantage arising from Bradley's discovery; the aberration of the stars is a direct proof of the motion of the earth in its orbit, and a new confirmation of the truth of the Copernican system. This system, indeed, is the basis of most of the great discoveries of Newton; and to those who can follow that sublime philosopher through all his calculations and enquiries, the Copernican hypothesis will want no other support than what he has given it: but this evidence is confined principally to men of science, who have entered into the depth of mathematical investigations, and are qualified to

judge of their validity. There are minds that require proofs more immediate and sensible, who judge of probability, not from calculations but from facts; and with these the observations of Bradley ought to have some weight. He has discovered, that the motion of light, combined with the motion of the earth, produces an apparent difference in the places of the fixed stars; and as this motion is found to affect all the stars differently, according to their situations, such a similarity of variations is sufficient to justify the truth of the cause upon which they were supposed to depend, and to shew that the system of the world, as restored by Copernicus, is conformable to nature and the order of things.

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O F T H E C O N S T E L L A T I O N S , A N D T H E P H Æ N O M E N A
O F T H E F I X E D S T A R S .

TH E heavens are divided by astronomers into three regions, called the northern and southern hemispheres, and the zodiac; and in order that the fixed stars may be treated of according to their true positions and situations, they have been classed under the outlines of certain imaginary figures of birds, beasts, and other animals, which are called Constellations. The number of these in the northern hemisphere is 36; in the southern 32; and in the zodiac 12: and as there are some stars that admit of no regular arrangement, they are called unformed stars; and others, from their cloudy appearance, are comprized under the name of Nebulæ.

This division of the starry firmament into Constellations is of the highest antiquity. Bootes and the Bear are spoken of both by Homer and Hesiod; Arcturus, Orion, and the Pleiades, are mentioned in the book of Job; and there is scarcely any ancient author in which the names of some of the most remarkable ones are not to
be

be found. But to trace the origin of this invention, and to shew why one animal had the honour of being advanced to heaven in preference to another, is no easy task. Mr. Fréret, the Abbe la Pluche, and several other writers of considerable eminence, have ransacked all the legends of fabulous history for the illustration of this subject; but, except in a few obvious instances, no consistent and satisfactory account has yet been given.

Most of the memorable events and customs of ancient times were involved in obscure hieroglyphical representations; and many of the constellations are probably symbols of this kind. The division of the zodiac into twelve signs, of thirty degrees each, has a manifest relation to the twelve months of the year; and the animals, by which those signs are denoted, were perhaps designed as emblems of the different productions of nature in those seasons over which they preside; or as indicating certain circumstances relating to the motion of the sun in the heavens. Many of the constellations also appear to have been formed in honour of certain heroes and celebrated personages, whose memory they were meant to perpetuate; and any vague resemblance of a crown, a cross, or a triangle, would occasion the parts of the heavens where they were found to be called by those names. This manner of classing the stars is indeed so natural,

natural, that it is found among the Chinese, the Americans, and many other nations that seem to have had no intercourse with the rest of the world.

The heavens being thus divided, it was more easy to reduce the stars into order, and to find their number, than it would have been without such a contrivance. And though this be considered, by the uninstructed part of mankind, as an impossible thing, it has been often attempted both by the ancients and moderns. Hyparchus the Rhodian, who lived about 120 years before Christ, was the first among the Greeks that engaged in this singular enterprize; “daring (according to Pliny) to undertake a thing which seemed to surpass the power of a deity; that is, to number the stars, and to ascertain their true places in the heavens.” It was imagined in those days, as it is at present, that, in a fine winter’s night, when the sky is perfectly clear, the stars which may be seen in the firmament are beyond the reach of all calculation; and that

To count their numbers, were to count the sands
That ride in whirlwinds the parch’d Lybian air;
Or waves that, when the blustering north embroils
The Baltic, thunder on the German shore.

ARMSTRONG.

This, however, is a mistaken notion: the number of stars, as I have observed in a former letter,

letter, that can be seen by the naked eye in the whole visible hemisphere, is not above a thousand. Hyparchus, from his own observations, and those of the ancients that preceded him, inserted in his catalogue only 1022, annexing to each of them the latitude and longitude which they had at that time. Ptolemy added four to this number; and many others were afterwards discovered by different astronomers, who applied themselves to this subject. But of all the catalogues of the stars which have hitherto been made, that which is given by Flamsteed, in his *Historia Cœlestis*, is the most complete. The number of stars inserted in this catalogue is about 3000; which number has been since augmented to near 5000, by Dr. Halley, *Monf. de la Caille*, *Monf. le Monnier*, and others; and from the accuracy of their observations, there is scarcely a star to be seen in the heavens, whose place and situation is not better known than that of most cities and towns upon the earth.

And in order that the memory may not be burthened with a multiplicity of names, astronomers mark the stars of every constellation with a letter of the Greek alphabet; denoting those that are the most conspicuous by α , the next by β , and so on in succession; by which means they can be spoken of with as much ease as if each had a separate name. This was the invention of John Bayer, a native of Augs-
burg,

burg, in Germany, who first introduced it about the year 1603, in his charts of the constellations. But the best work of this kind which has yet been executed for representing the constellations, and the stars of which they are composed, is the *Atlas Cœlestis* of Flamsteed, or the two planispheres of Senex, which, together with the stars discovered by M. de la Caille in the southern hemisphere, contain an entire map of the heavens; so that by means of these charts, or a good celestial globe, we can easily know any particular star that is discernible to the eye, and tell the constellation to which it belongs.

But of all the phænomena of nature, the sudden appearance of new stars, and the disappearance of old ones, is one of the most singular, and difficult to be accounted for. A circumstance of this kind first led Hyparchus to compose his catalogue of the stars, in order that posterity might be apprized of the true state of the heavens at that period; and since his time many changes of the same nature have been observed, both by ancient and modern astronomers. Some of the larger stars have not the same precise situations that are attributed to them by the ancients, and others are found to have a periodical increase and decrease of magnitude. The bright stars, Sirius and Arcturus, have been observed to change their places, by moving towards the south about two or three minutes of a degree in
a cen-

a century; and the stars, Aldebaran and Aquila, have also a like motion, but something slower, and less easy to be determined.

Among the new stars that have been discovered by the moderns, that which appeared on the 8th of November, in the year 1572, was the most remarkable. Its splendor exceeded that of Jupiter when nearest the earth, and was such that it could be seen in the day-time. Cornelius Gemma first observed it in that part of the heavens which is called Cassiopeia's Chair, forming a perfect rhombus with the three stars α , β , and γ , of that constellation; and Tycho Brahe, who saw it on the 11th of the same month, found its longitude to be 6 degrees 54 minutes of Taurus, and its latitude 53 degrees 45 minutes north. About the beginning of December it began to diminish, becoming gradually less and less till the month of March 1574, when it totally disappeared, and has never been seen since. It was found to have no parallax, nor any apparent motion, and was sparkling and clear like the rest of the fixed stars.

On the 10th of October 1604, the scholars of Kepler discovered another new star in the right leg of Serpentarius, which was nearly as brilliant as the former. Its right ascension, as observed by Kepler, was constantly 256 degrees 57 minutes, and its declination 21 degrees $1\frac{1}{2}$ minutes south. This star also had no parallax, nor any apparent motion;

motion; and after suffering a gradual diminution of its light, it totally disappeared about the beginning of January 1606. Neither of these stars had either a tail or hair, to countenance any idea of their being comets; and as they had no parallax, it is evident that they must have been at a greater distance from the earth than Saturn.

The first star that was observed to have a periodical change of brightness is that marked θ by Bayer, in the neck of the Whale. It was discovered by David Fabricius on the 13th of August, 1596. At the time of its greatest brightness, it appears equal to a star of the third magnitude; and is scarcely ever so small but that it may be seen with a six feet telescope. Hevelius assures us, that it once entirely disappeared for four years; and M. Cassini, who observed it at the time of its greatest splendor, about the beginning of August 1703, found it to be of the third magnitude, as had before been supposed by Fabricius. In this time it had made about 117 revolutions, which at a mean, fixes its period at 334 days; but it has since been found that its changes are very irregular.

Three changeable stars have also been observed in the neck of the Swan. The first is that near the star γ in that constellation. Its greatest lustre is less than one of the third magnitude, and it gradually diminishes till it is equal

to one of the sixth. Its changes are also far from being regular, and do not take place till after an interval of ten or more years. The next is that marked χ : this is more regular in its returns than the former, though its magnitude is seldom greater than the sixth, and its period is settled at about 405 days. The third was seen near the head of the Swan, on the 20th of June 1670, and appeared of the third magnitude, but was so far diminished in October following, as to be scarcely visible. In the beginning of April 1761, it was again seen, rather brighter than before; and after several other changes, by which its period was judged to be about ten years, it disappeared on the 30th of March 1762, and has not been seen since.

The star Algol, or Medusa's head, has been long since observed to appear of different magnitudes at different times; but the discovery of its period is due to John Goodricke, Esq; of York, who first began to observe it about the beginning of the year 1783. It changes continually from the first to the fourth magnitude; and the time employed from its greatest diminution to its least, is found at a mean to be two days, twenty hours, forty-nine minutes, and three seconds. The change is thus: during four hours, it gradually diminishes in lustre; and in the succeeding four hours it regularly recovers its first magnitude. In the remaining part of

the period it invariably preserves its greatest lustre; and after the expiration of this term the diminution again commences.

Many opinions have been entertained concerning the cause of these phænomena, but as they are frequently incongruous and unsatisfactory, I shall only give you a few of the most plausible. If the light of the sun and stars be owing to a combustion similar to that which is required to produce light in most other substances, it will follow, that when the inflammable matter is decomposed the ignition will cease. Or, if a mass of matter, adapted for inflammation, begin by any cause to burn, its ignition and emission of light will commence at the same time. So that if these considerations be applied to the fixed stars, the appearance of some, and the disappearance of others, will be rationally accounted for; and as there are no data by which their periods can be ascertained, they may last any given time according to circumstances.

The spots on the sun have also afforded a conjecture concerning the cause of a periodical change of brightness in some of the fixed stars. For if a star be supposed to turn upon its axis, and to have a spot of considerable magnitude upon some part of its surface, it will appear much brighter when the spot is not on the visible disc, than when it is wholly exposed to our sight; and as it is more or less seen an altera-

tion of light will take place accordingly. But against this hypothesis it must be observed, that the phenomena in general do not agree with the supposition; for the brightness or obscurity that prevails in some of the changeable stars for more than half their periods, seems to prove that the different appearances they exhibit cannot be owing to a defalcation of light on any part of their surfaces.

Another conjecture, which appears something more probable, is, that if a star, by a swift revolution, be made to assume and preserve a flattened figure, and its axis have a rotation similar to that of the earth, it will be much less bright when its edge is presented to the observer, than when the visible disc is projected broader. Or, lastly, if a planet be supposed to revolve round a star, in the same manner as the planets in our system revolve round the sun, it may occasion certain periodical eclipses, of such magnitudes and durations, as are sufficient to account for all the changes in its appearance. Thus, for instance, if an opaque planet, whose diameter is not much less than that of Algol, be supposed to revolve about that star, in a plane, whose orbit passes through the earth, it will occasion certain eclipses, which by supposing its period and distance to be properly regulated, may be made to agree with all the observed appearances.

Several

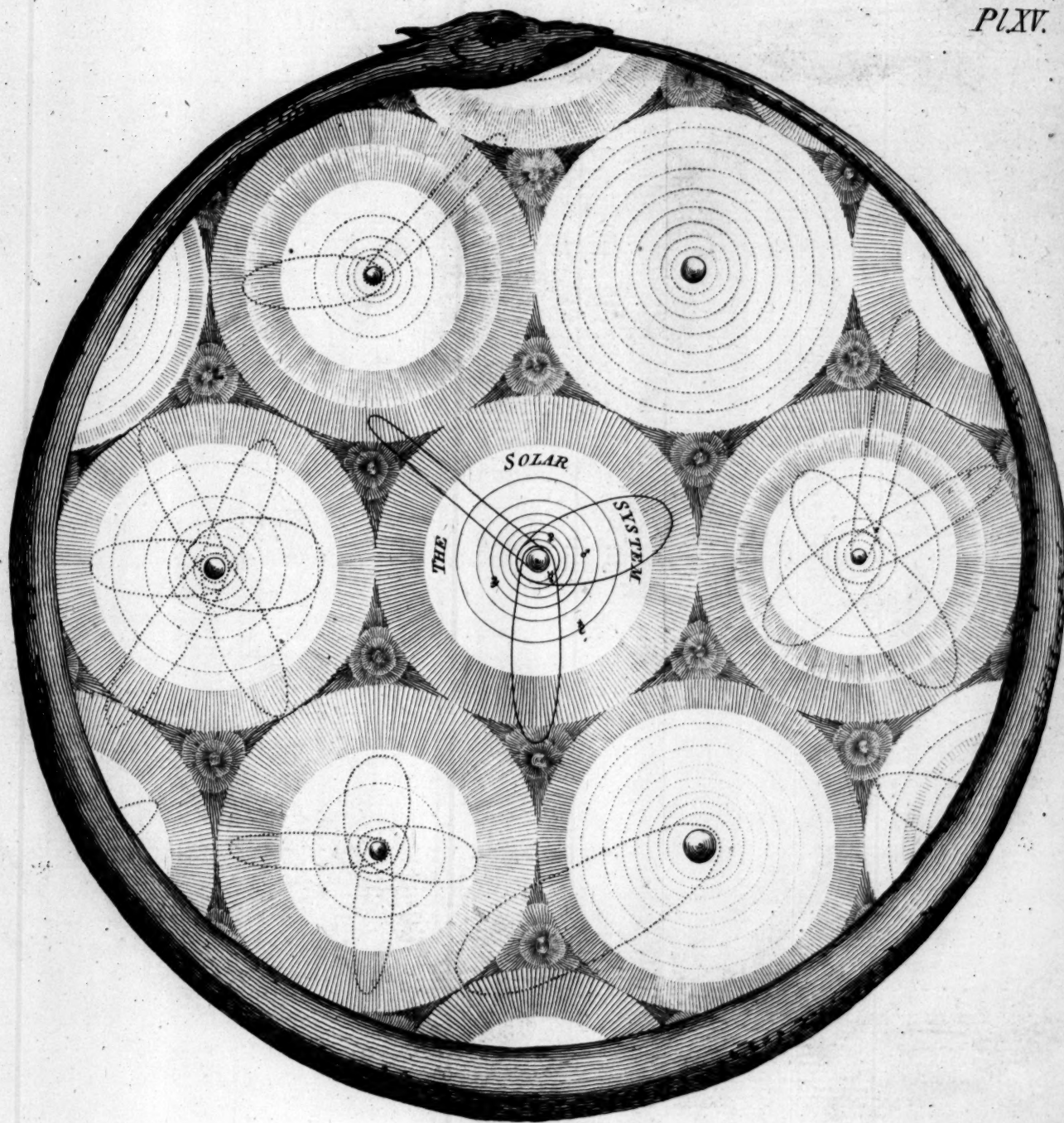
Several other changes in particular stars have been observed by different astronomers, but as they are less conspicuous I shall pass them over in silence. Many of the fixed stars have also been found to consist of two, or to appear as if they were double. The number of these was formerly thought to be very small; but the celebrated Mr. Herschel, who stands unrivalled for the excellence of his instruments, and his skill in using them, has discovered upwards of 400.

Besides these, there are also many *nebulæ*, or parts of the heavens, which appear brighter than the rest. One of the most obvious to common notice is that large irregular zone, or band of light, which crosses the ecliptic in Cancer and Capricorn, and is inclined to it in an angle of about sixty degrees. Other *nebulæ* are seldom to be distinguished by the eye from small stars; but if the telescope be applied to them, they seem to be luminous spots of various figures, and in some instances with stars in them. The number of *nebulæ* was formerly imagined to be about 103; but Mr. Herschel, previous to the month of April 1784, had discovered 466 more. Many of these are resolvable by the telescope into clusters of small stars; and telescopes of a still greater power resolve those *nebulæ* into stars, which, in instruments of less force, appear like white clouds; so that there is great reason

to conclude that they all consist of clusters or large masses of stars, at a prodigious distance from our system.

Mr. Herschel is of opinion, that the starry heaven is replete with these nebulae, and that each of them is a distinct and separate system, independent of the rest. The milky-way he supposes to be that particular nebula in which our sun is placed; and in order to account for the appearance it exhibits, he supposes its figure to be much more extended towards the apparent zone of illumination than in any other direction; which is a supposition that appears allowable, from the observations he has made on the figures of other nebulae of a like kind. These are certainly grand ideas, and whether true or not, do honour to the mind that conceived them.

This notion, indeed, of forming the stars into systems is not a new one. The ingenious Mr. Michell, about twenty years ago, had the same idea. He observed that there were many large spaces in the heavens where no stars were to be seen; and others in which a number of very considerable ones appear near together, in the midst of several smaller ones. The Pleiades, for instance, are composed of six remarkable stars, which are placed in the midst of a number of others, that are all between the third and sixth magnitude; and as there are only about 1500
stars



T. Gonder Sculp.

stars in the whole heavens, which are visible to the naked eye, he calculated, by the doctrine of chances, that among all this number, if they had been dispersed arbitrarily through the celestial vault, it was five hundred million to one, that six of them should be placed together in so small a space,

It is therefore so many chances to one that this distribution was the work of design, or that there is a reason or cause for such an assemblage; and in a universe where every thing is governed by immutable laws, this degree of probability is exceedingly strong. The stars, therefore, PL. XV, which are thus grouped, are most probably systems analogous to the solar one; and our sun, who appears to be the lord of the universe, is most likely only a star that belongs to some of those systems that are interspersed through the regions of the infinite expanse. This is conformable to the designs of Nature in all her operations. Our planetary system demonstrates, that she unites and connects several bodies together in order to compose a whole; and it is highly probable, that all her works are conducted upon the same plan.

But a necessary consequence of this idea is, that these different systems should be mutually balanced among themselves by some general cause; and this is most probably effected by means of one system, which regulates the others

by the number of bodies it contains ; or perhaps by one body, which is more powerful than all the rest, and round which they all move. Here then is a gradation in the most magnificent works of nature, like that which we perceive among the lower orders of existences. The satellites accompany the planets ; the planets follow the sun ; and the sun himself is connected with a system of stars, over which presides another sun of superior magnitude and force ; and so on through a number of variations and degrees, which not even the imagination itself can trace.

The immense distance of these vast bodies, is also another consideration that overpowers all our faculties : James Cassini attempted to shew, that the annual parallax of Sirius, which is the nearest of all the fixed stars, is about six seconds ; and from this it would follow, that its distance from our earth is near eighteen thousand times greater than that of the sun. But from all the observations, hitherto made, it appears, that the parallax of the stars is altogether insensible, and consequently their distance must be such that no calculation can estimate. If the stars, therefore, be considered as suns, having a number of planets moving round them, like those that compose the solar system, it will be no argument against their existence, to say that we do not see them ; for as the suns themselves are at such distances as to appear like so many luminous points,

points, the planets, which shine only by reflection must be totally invifible.

Dr. Halley has a very ingenious obfervation upon the magnitudes and diftances of the fixed ftars: He remarks, that there can be only thirteen points upon the furface of a fphere, whose diftances from each other fhall be all equal to the radius; and as the neareft fixed ftars are fupposed to be as far from each other as they are from the fun, he fupposes them to be placed in the furface of an imaginary concave fphere, which has the fun for its center; and from thence infers, that there can be only thirteen ftars of the firft magnitude. The ftars of the fecond magnitude he fupposes to be twice as far diftant from the fun as thofe of the firft, and by placing them in like manner in the furface of a fphere, at fuch diftances from each other as are equal to half the radius, their number will be fifty-two. At a triple diftance the furface of the fphere would contain an hundred and feventeen, which is the number of ftars of the third magnitude; and fo on. This fupposition is nearly agreeable to the ufual method of claffing the ftars of the firft and fecond magnitude; and if the diftribution of them could be made according to their true magnitudes, it would probably be found perfectly juft.

Halley conceived the whole folar fyftem, together with all the fyftems of the ftars, to be in
motion

motion round some point which is the center of gravity of the whole ; and in pursuing this idea, the following reflections naturally occurred to him : “ If, says he, the number of stars be finite, and occupy only a part of space, it will follow that they must be surrounded by a void. But as this void can have no action upon the bodies which it environs, those bodies must exert all their force upon one another, without equilibrium, and without compensation. Those which are at the extremities, or near the borders of the void, will be strongly and continually attracted by those near the center ; and these efforts continued and multiplied through a number of ages, must at length draw all the suns and planets into that point, and form one immense mass, which must for ever remain there, without action and without motion. But if, on the contrary, the number of stars be infinite, and the system without bounds, all the forces will be balanced among themselves ; the suns and planets will preserve the paths prescribed them ; and the order of the universe will be perpetually the same.” These are the conceptions of a vigorous mind ; but they lead us into a labyrinth where there is no clue to be found ; infinity can be comprehended by God alone.

L E T-

L E T T E R XX.

OF THE PHÆNOMENA AND AFFECTIONS OF THE
SUN, MOON, AND PLANETS.

THE sun was generally considered by the ancients as a globe of pure fire; but from a number of dark spots, which, by means of a telescope, may be seen on different parts of his surface, it appears that this opinion was ill-founded. These spots consist, in general, of a nucleus, or central part, which appears much darker than the rest, and seems to be surrounded by a mist or smoke; and they are so changeable in their situation and figure, as frequently to vary during the time of observation. Some of the largest of them, which are found to exceed the bulk of the whole earth, are often to be seen for three months together; and when they disappear, they are generally converted into faculæ, or luminous spots, which appear much brighter than the rest of the sun. About the time they were first discovered by Galileo, forty or fifty of them might be frequently seen on the sun at a time; but at present we can seldom observe more than thirty; and there have been periods

periods of seven or eight years, in which none could be seen.

Father Scheiner, who was contemporary with Galileo, has given us an anecdote, which will serve to shew how this discovery was at first received. He imagined himself to have been the only person who had ever seen this curious phænomenon, and having communicated the result of his observations to the provincial of his order, received the following answer. " This subject, my dear Sir, is not mentioned by any of the ancient philosophers: I have read my Aristotle several times over, and have found nothing like what you speak of. Do not expose yourself by propagating these absurdities; for be assured, that it is only some defect in your eyes or your glasses, which makes you imagine that you see spots in the sun." And so firmly persuaded was this zealous Peripatetic that every thing was contained in the Greek philosophy, that neither the most rational arguments, nor the evidence of his senses, could convince him to the contrary: he inflexibly adhered to this opinion, and would not suffer Scheiner to publish his discovery, till he had promised him to do it under a fictitious name.

The general opinion concerning the solar spots is, that they are occasioned by the smoke and opaque matter thrown out by volcanos or burning mountains of immense magnitude; and that when the eruption is nearly ended, and the
smoke

smoke dissipated, the fierce flames are exposed, and appear like faculæ or luminous spots. M. de la Hire imagined the sun to be in a continual state of fusion, and that the spots which we observe are only the eminences of large masses of opaque matter, which, by the irregular agitations of the fluid, sometimes swim upon the surface, and at other times sink and disappear. Others have supposed them to be occasioned by a number of planets, circulating round the sun, at a small distance from his surface. But Dr. Alexander Wilson, of Glasgow, has established from observation, that most, if not all the spots, are excavations in the luminous matter that environs the sun's body, and which is probably of no great depth.

The motion of the spots is from east to west; and as they are observed to move quicker when they are near the central regions, than when they are near the limb, it follows that the sun must be a spherical body, and that he revolves on his axis in a contrary direction, or from west to east. The time in which he performs this revolution, as observed by Cassini, is twenty-five days, fourteen hours, and eight minutes; and from the line of the motion of the spots, which is sometimes straight, but oftener crooked or elliptical, it is discovered that his axis is not perpendicular to the plane of the ecliptic, but inclined

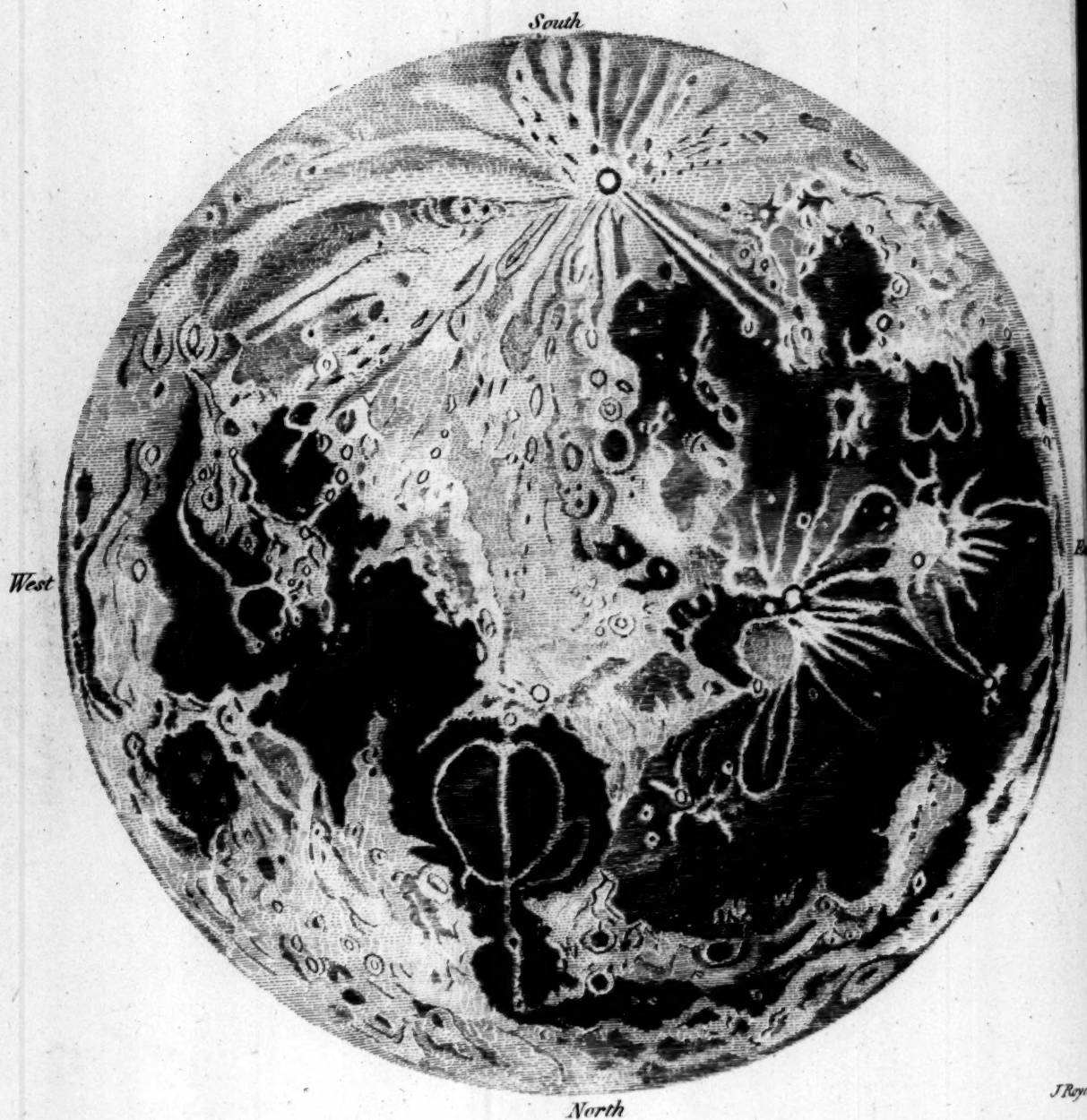
inclined to it so as to make an angle with the perpendicular of about seven degrees and a half.

The zodiacal light is another singular phænomenon, which accompanies the sun, and is usually attributed to his atmosphere. It begins to appear a little before sun-rise, and seems at first sight like a faint, whitish zone of light, resembling the milky-way, with its borders ill terminated, and scarcely to be distinguished from the twilight, which is seen commencing near the horizon. It is then but little elevated, and its figure nearly agrees with that of a flat lenticular spheroid, seen in profile. As it rises above the horizon it becomes brighter and larger to a certain point, after which the approach of day renders it gradually less apparent, till it becomes quite invisible. The direction of its longer apparent axis is observed to be in the plane of the sun's equator; but its length is subject to great variations, so that the distance of its summit from the sun varies from 45 to 120 degrees.

But of all the discoveries which have been made by means of the telescope, those relating to the moon are the most curious and interesting. This planet being much nearer to us than any of the rest, is the first that offers herself to our inspection, and is the best adapted for examination. By viewing her with the naked eye we discern a number of spots, which the imagination

The Telescopic Appearance of the Moon.

Pl.



J. Royce

nation naturally supposes to be seas, continents, and the like; and on a more accurate inspection, with a telescope, the hypothesis of planetary worlds receives additional confirmation. Vast cavities and asperities are observed upon various parts of her surface, exactly resembling vallies and mountains; and every other appearance seems to indicate, that she is a body of the same nature with our earth. We can scarcely hope to make optical instruments sufficiently perfect to render animals visible at such a distance; but Mr. Herschel, whose telescopes are far superior to any that were ever before executed, is said to have discovered a manifest volcano in the moon; and if his improvements are pursued, we may, perhaps, receive indubitable proofs of her being an inhabited world.

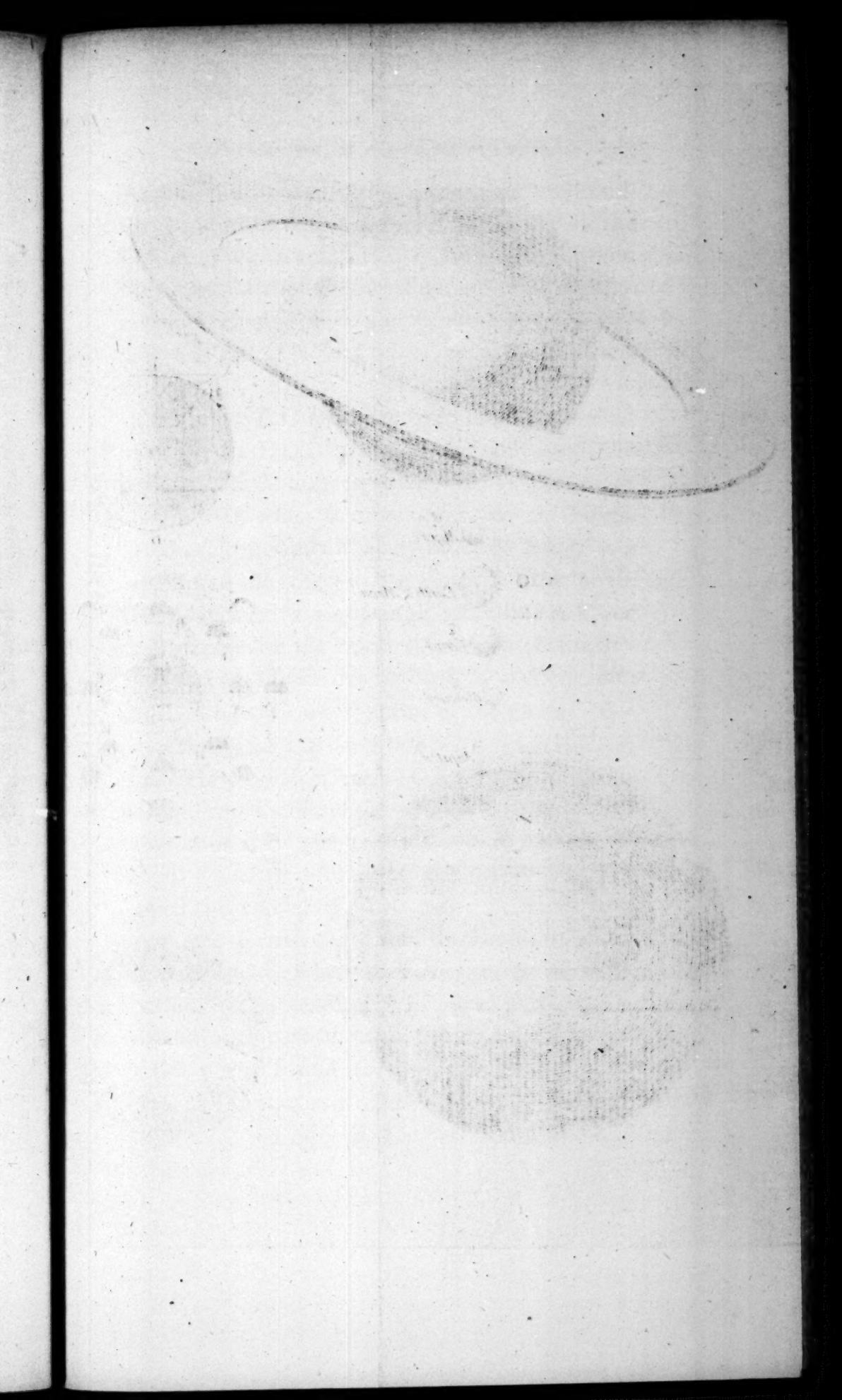
Galileo, when he first saw this planet through his telescope, was struck with the singularity of her appearance; and being free from the prejudices of the schools, soon discovered a striking similitude between her and the earth. This is what Milton finely alludes to when he describes the shield of Satan, in the first book of his *Paradise Lost*.

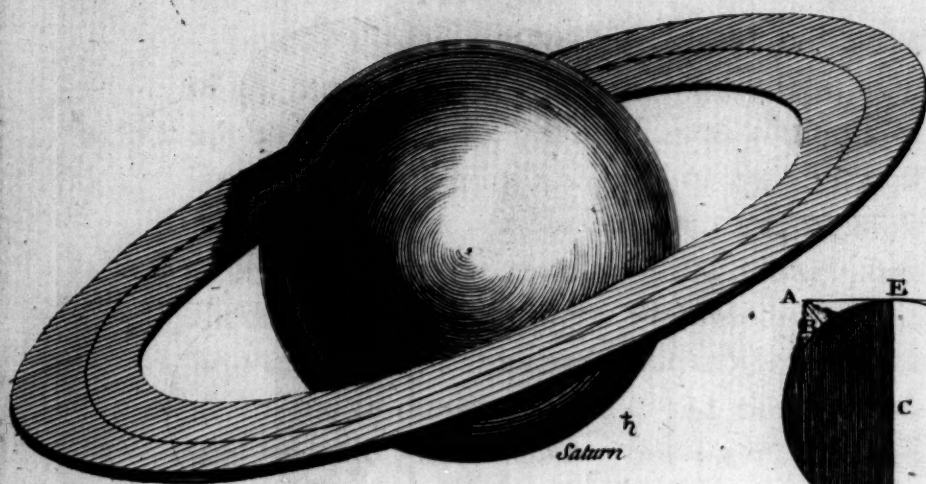
—————“ The broad circumference
Hung on his shoulders like the moon, whose orb
Through optic glass the Tuscan artist views,
At evening from the top of Fesolè,
Or in Valdarno, to descry new lands,
Rivers or mountains in her spotty globe.”

Several

Several astronomers have given us exact maps of the moon, with the figure of every spot, as it
 PL. XVI. appears through the best telescopes, distinguishing each of them by a proper name. Riccioli divided the lunar regions among those philosophers and astronomers, who have distinguished themselves by advancing the knowledge of the heavens, giving the names of the most celebrated characters to the largest spots, and those of less eminence to the smaller. But Hevelius, who did not approve of this distribution, denoted the different parts of the moon by such geographical names, as belong to the several islands, countries, and seas of our earth, without any regard to their situation or figure. The method of Riccioli, however, is that which is now generally followed, as the names of Hyparchus, Tycho, Copernicus, &c. are more pleasing to astronomers, than those of Africa, the Mediterranean Sea, Sicily, and Mount Ætna.

That the spots in the moon, which are taken for mountains and vallies, are in reality such, is evident from their shadows. For in all situations of the moon, the elevated parts are constantly found to cast a triangular shadow, in a direction opposite to that of the sun; and, on the contrary, the cavities are always dark on the side next the sun, and illuminated on the opposite one; which is exactly conformable to what we observe of hills and vallies on the earth,
 And





♂ Jupiter



Fig. 1.

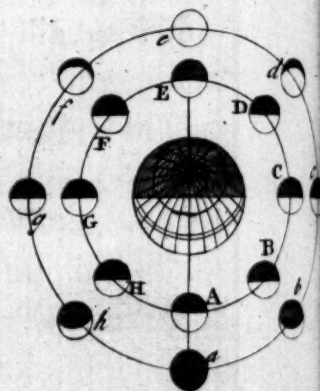
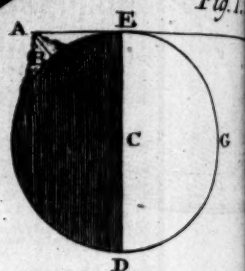
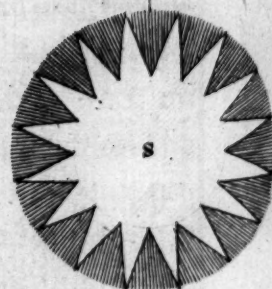


Fig. 2.



And as the tops of these mountains are considerably elevated above the other parts of the surface, they are frequently illuminated when they are at a considerable distance from the confines of the enlightened hemisphere, and by this means afford us a method of determining their heights.

Thus, let $E G D$ be the moon's enlightened hemisphere, $E C D$ the diameter of the circle bounding light and darkness, and A the top of a mountain when it first begins to be illuminated: Then, since the ray of light $S E A$ is a tangent to the moon at the point A , the angle $C E A$ will be a right angle; the line $A E$, or the distance of the point A from the boundary $E C D$, can also be determined by observation; and $C E$ is the known radius of the moon. We have therefore the two sides $C E$ and $E A$, of the right-angled triangle $C E A$, from whence we can find the third side $C A$; and subtracting the radius $C B$, the remainder $A B$ will be the height of the mountain required. Riccioli observed the top of the hill called St. Catherine, upon the fourth day after the new moon, to be illuminated when it was distant from the confines of the enlightened hemisphere about one-sixteenth part of the moon's diameter; and by this means found its height to be nine miles: So that from this, and other similar observations,

Pl. XVII.
fig. 1.

it appears, that the lunar mountains are much higher than any we have upon the earth.

Most astronomers are of opinion that the moon has no atmosphere, because she is never obscured by clouds or vapours, and because the fixed stars, at the time of an occultation, disappear instantaneously, without any gradual diminution of their light. But if we consider the effects of days and nights, which are near thirty times as long as with us, we may readily grant that the phænomena of vapours and meteors must be very different. And besides, the vapourous or obscure part of our atmosphere is only about the 1980th part of the earth's diameter, as is evident from the height of the clouds, which is never above four miles; and therefore as the moon's apparent diameter is only about thirty-one minutes and an half, or 1890 seconds, the obscure part of her atmosphere, when viewed from the earth, must subtend an angle of less than one second; which is so small a space, that observations must be extremely accurate to determine whether the supposed obscuration takes place or not.

In looking at the moon through a telescope we constantly observe the same face, and from this it is evident that she turns only once round upon her axis in the time of every periodical revolution; so that the inhabitants of the moon have but one day and night in the course of a
 I month.

month. This rotation on her axis, which is the most uniform motion the moon has, occasions a seeming irregularity which is called her libration. For as the moon's motion in her orbit is not uniform, the effect it has in turning her face from the earth is likewise subject to the same irregularities; so that, for instance, in the swiftest part of her revolution, her face is turned from the earth something more than her rotation on her axis turns it the contrary way, and therefore she will appear to have a small motion on her axis towards the east.

In the slower part of her revolution, the contrary will be seen; for then the rotation on her axis prevailing, brings the western parts into sight, and occasions the eastern to disappear. This is called libration in longitude; besides which there is another kind of libration, that arises from the moon's axis being inclined to the plane of her orbit; on which account sometimes one of her poles, and sometimes the other, is inclined towards the earth. In consequence of this we see more or less of the polar regions at different times, and therefore this motion is called libration in latitude.

One of the most remarkable circumstances attending the moon is the continual change of figure to which she is subject. Sometimes she appears perfectly full, or circular, at other times only half or a quarter illuminated, changing

through a great variety of figures. And as these changes are always the same at the same elongation from the sun, they prove that she receives her light from that luminary: for the moon being enlightened on that side only which faces the sun, a greater or less quantity of that enlightened part will be visible, according as it is turned towards us, or from us; and her figure will consequently appear to vary through the whole of her revolution. This may be easily illustrated by means of an ivory ball, which being held before a candle in various positions, will present a greater or less portion of its illuminated hemisphere to the view of the observer, according to its situation.

Pl. XVII.
fig. 2.

The same thing may also be shewn thus: Let S represent the sun, E the earth, and A, B, C, D, &c. the moon's orbit: then when the moon is at A, in conjunction with the sun S, her dark side being entirely turned towards the earth, she will disappear, as at *a*, and is now called the new moon. When she comes to her first octant at B, or has gone through an eighth part of her orbit, a quarter of her enlightened hemisphere will be turned towards the earth, and she will then appear horned, as at *b*. When she is at C, or has gone through a quarter of her orbit, she shews us one half of her enlightened hemisphere, as at *c*, and is then said to be a quarter old. At D she is in her second octant, and by shewing us more of her enlightened hemisphere than at C, appears

appears gibbous, as at *d*. At E her whole enlightened side is turned towards the earth, and now she appears round, as at *e*, and is said to be at her full. In her third octant at F, part of her dark side being turned towards the earth, she again appears gibbous, and is on the decrease, as at *f*. At G we see just one-half of her enlightened side, at which time she appears still farther decreased, as at *g*. When she comes to her fourth octant at H, we only see a quarter of her enlightened hemisphere, which occasions her to appear horned, as at *h*. And at A, having now completed her course, she again disappears, or becomes a new moon as before.

The moon's path or orbit is inclined to the plane of the ecliptic in an angle of about five degrees and a third; and her periodical revolution round the earth is performed in twenty-seven days, seven hours, forty-three minutes, eleven seconds and an half: but in this motion there are many irregularities, so that the determination of her true place in the heavens, for any given instant of time, has ever been considered as a problem of the utmost difficulty. Newton was the first who pointed out the source of these irregularities, and the mode of investigating them; and from the principles he has laid down we have gradually obtained a more exact theory of the moon than could have been expected by former astronomers. Mayer's lunar tables, in particu-

lar, are considered as extremely accurate; for being compared with above two hundred observations, as well ancient as modern, they were seldom found to differ above a minute from the truth.

But as the theory of the moon's motion is too intricate to admit of a popular illustration, I shall leave this subject for the present, and proceed to give you some account of the rest of the planets. Mercury, as I have already mentioned, is too near the sun to be often seen; but Venus, being higher in the system, and more easy to be observed, is found to be diversified with spots, and to have all the various phases and appearances of the moon. Mountains and vallies have also been discovered in this planet, by means of good instruments; and from the motion of her spots it is determined, that she revolves round her axis from west to east in the space of about twenty-three hours.

The face of Mars, on the contrary, is always found to be round and full, as his superior situation requires; excepting at the time of the quadratures, when a small part of the unenlightened hemisphere being turned towards us, his disc appears like the moon about three days after the full. This planet is also diversified with spots like the moon, by which his diurnal revolution is ascertained in the direction from west to east; and from his ruddy and obscure appearance,

pearance, as well as from other circumstances, it is concluded that his atmosphere is nearly of the same density with that of the earth. Mr. Herschel has observed that two circles surrounding the poles of this planet, are very white and luminous, which is probably owing to great quantities of snow lying there without melting.

The telescopic appearance of Jupiter affords a vast field for the curious enquirer. This planet is surrounded by several faint substances, resembling belts or bands, which are parallel to the plane of his orbit, and consequently to each other. They are not regular or constant in their appearance: for sometimes only one is to be seen, and sometimes five; and in the latter case two of them have been known to disappear during the time of observation. When their number is most considerable, one or more dark spots are frequently formed between the belts, which increase till the whole is united into one large dusky band. This planet is also diversified with a number of large spots, which are the brightest part of his surface; but, like the belts, they are subject to various mutations, both in their figure and periods.

That remarkable spot, by whose motion the rotation of Jupiter upon his axis was determined, first disappeared in 1694, and was not seen again till 1708, when it re-appeared exactly on the same part of his surface, and has been occasionally

seen ever since. It has been conjectured that these belts are seas, and that the variations observed, both in them and the spots, are occasioned by tides, which are differently affected according to the positions of his moons. The four satellites of Jupiter were first observed by Galileo, the 7th of January 1610, soon after the invention of the telescope, but the belts were not discovered till near twenty years afterwards.

Saturn is at too great a distance for us to distinguish those varieties which it is probable are upon his surface; but the faint appearance of a belt may sometimes be seen, resembling those of Jupiter. The ring which encircles the body of this planet, is inclined to the plane of the ecliptic in an angle of about thirty degrees, in consequence of which its apparent figure is continually varying. When the line of its nodes points directly towards the earth, the ring, presenting its edge to the observer, becomes invisible; and if the same line points directly towards the sun, the ring cannot be seen for want of illumination. But in general its figure is that of an oval, which is broader and narrower, according as the line of the nodes is further from or nearer to the above position.

This ring is like a large flat circle, surrounding the body of the planet, without touching it; its distance from Saturn being nearly equal to its breadth, which is about 21,000 miles. Some have

have imagined that it is composed of a vast number of satellites or moons, disposed in the same plane, which being seen at such a great distance, may, by means of their blended light, give the whole the appearance of a continued body. And indeed, if we consider how much the sun's light must be weakened before it can reach Saturn, such a glorious assemblage of moons will not appear an unnecessary appendage to this planet. The ring was first discovered by Huygens, about the year 1655, who likewise observed the fourth satellite; but the fifth, and the first three, were not discovered till several years afterwards.

As these are the most interesting particulars relating to the planets, I shall now proceed to give you some account of the comets, those erratic bodies, which the ancients considered as enormous meteors, formed in the atmosphere, and sent as harbingers of divine vengeance. This was the prevailing opinion as early as the time of Homer, who speaks of

—— “ The red comet, by Saturnia sent,
To fright the nations with a dire portent;
A fatal sign to armies on the plain,
Or trembling sailors on the wat'ry main.”

And a similar allusion is also given by Milton, who compares the indignation of Satan,
at

at being opposed in his passage by Death, to the burning of a comet,

“ That fires the length of Ophiúchus huge
In th’ arctic sky, and from his horrid hair
Shakes pestilence and war.”

Tycho Brahe, and Dominique Cassini, were the first among the modern astronomers who gave these bodies a place in our system; but they appear to have been unacquainted, both with their motion round the sun, and the true figure of their orbits. These particulars were left for the determination of Newton, who has discovered the paths they describe, and the laws to which they are subject. Their revolutions are now known to be performed in very long ellipses, whose lower focus is in or near the sun, being governed throughout by the same law, of describing equal areas in equal times, which is known to regulate the motions of all the other bodies in the system.

By observations of parallax it is also found, that at their first appearance they are nearer to us than Jupiter; from whence it is concluded that they are, in general, less than that planet; for if they were as large they would be seen as far off. In their motions round the sun they are also subject to the same irregularities as the planets; but as their orbits are extremely eccentric, those variations are much
more

more considerable. When they are near the sun, their motion is very rapid, and in the more distant parts of their orbits extremely slow; so that their vicissitudes in this respect are as much in the extreme, as what they undergo from heat and cold.

When a comet arrives within a certain distance of the sun, it emits a fume or vapour called its tail; which shows that they contain a portion of matter considerably more rare and volatile than any on the earth; for the tail begins to appear when they are yet in a higher, and consequently a colder region, than Mars. In every situation of the comet the tail is always directed to that part of the heavens which is nearly opposite to the sun; and is always greater after the comet has passed its perihelium, than during its approach towards it, being greatest of all when it has just left that point.

That part of a comet's orbit, which comes under our inspection, is so small in proportion to the whole, that it differs but little from a parabola, for which reason the dimensions of their orbits and periodical times cannot be ascertained, with any degree of precision, from a single observation. But from the re-appearance of several comets after long intervals of time, in the same region of the heavens, and from their being found to move in the same curve, it is evident that their revolutions must be performed in certain stated times,
like

like those of the planets. This indeed has been demonftrated by Dr. Halley, who, from the theory of Newton, has calculated tables for determining the orbits of the comets, which, in feveral instances, have been found agreeable to obfervation.

The comet that appeared in the year 1661, was feen before in the fame orbit, and under the fame circumftances, in the year 1532, which fhows its period to be 129 years; and if it reappear in the year 1790, its identity will be ftill further confirmed. So, alfo, the comet that appeared in the years 1456, 1531, 1607, 1682, and 1759, is determined to revolve in a period of about 76 years. And that remarkable comet which was obferved in the year 1680, is fhewn to be the fame with the one that appeared in the year 1106, its period being 575 years.

The diftance of this comet from the fun, when in its perihelium, was to the diftance of the earth from the fun, as 6 to 1000; its heat, therefore, at that time, was to the heat of the fummer's fun with us, in the ratio of about 28000 to 1: fo that, according to Newton, the furface of this comet, fupposing it to be compofed of a matter like our earth, would have acquired a heat, about 2000 times greater than that of red hot iron; which is fo intenfè, that vapours, exhalations, and every volatile matter
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must have been immediately consumed and dissipated.

The number of comets belonging to our system is unknown; but from the accounts of the ancients, and the more accurate observations of the moderns, it is ascertained, that more than four hundred and fifty had been seen, previous to the year 1771; and when the attention of astronomers was called to this object, by the expectation of the return of the comet of 1759, no less than seven were observed in the course of as many years. From this circumstance, therefore, and the probability that most of the comets of small apparent magnitudes were overlooked by the ancients, it is reasonable to conclude, that their number is considerably beyond any estimation that can be made from the observations we now possess.

But the number of comets whose orbits are settled with sufficient accuracy for us to ascertain their identity when they appear again, is about fifty-nine, reckoning as late as the year 1771. The orbits of most of these are inclined to the plane of the ecliptic in large angles, and in their periheliums they come much nearer the sun than the earth does. Their motions in the heavens are also various, or different from those of the planets; some moving in consequentia, or according to the order of the signs, and others in antecedentia, or a contrary direction; but from
a com-

a comparison of the whole it has been found, that the number whose motions are retrograde is nearly equal to the number whose motions are direct.

These different motions of the comets, and the various inclinations of their orbits to the plane of the ecliptic, could never have been the work of chance, but must have arisen from wisdom and design. For had their orbits been nearly coincident with that of the earth, the two bodies might have arrived at the point of intersection at nearly the same time, and by their shock have occasioned the most fatal consequences to our globe. But of all the comets that have hitherto been observed, there are none that are in the least likely to give any disturbance to the earth. Should any of them approach so near us as to be more attracted by the earth than the sun, we might indeed, by that means, acquire another moon, which would be a change to our advantage, rather than a subject of terror and dismay.

Dr. Halley attempted to show, that the celebrated comet of 1680 was the same with that which was seen about forty-six years before Christ, or soon after the death of Julius Cæsar; and after having discovered its period to be about 575 years, he concluded that this comet must also have appeared near the time of the universal deluge, and that it was probably the occasion of that catastrophe. This he imagined

was

was effected by the immense quantity of humid vapours which composed its tail: and Mr. Whiston, who has supported this conjecture with all his force, was likewise of opinion, that the general conflagration will be occasioned by our being involved in the tail of the same comet, after it has been prodigiously heated in its passage from the sun.

Sir Isaac Newton, on the contrary, conjectured, that this, as well as all the other comets, coming nearer and nearer to the sun in every revolution, would at length fall into this luminary, and serve as aliment or fuel to supply the loss of matter which must arise from the continual emission of the particles of light. These, however, are mere hypotheses, and as such, but of little value. The same also may be said of every thing that can be advanced concerning their being inhabited worlds: for if animals can exist there, they must be creatures very different from any that we have the least conception of. Some, who have indulged themselves in visionary ideas of this kind, have imagined, from the prodigious vicissitudes of heat and cold which they are subject to in different parts of their orbits, that they are the receptacles of reprobated spirits; and others, with equal propriety, place the infernal dominions in the sun.

It must be observed, however, that the conjectures concerning planetary worlds are not
so

so exceptionable as those relating to the comets. For as the earth is shewn to be a planet similar to the other five, we reasonably conclude by analogy, that they must be designed for the same purposes, though from their different proportions of heat and cold, it is not credible that beings of our make and temperature could live upon them. This, however, can scarcely be affirmed of all the planets; for the warmest climate on Mars is not colder than many parts of Norway or Lapland in the spring; though Jupiter and Saturn, it must be confessed, are much more so than any of the inhabited parts of our globe.

It also appears, that the greatest heat on the planet Venus, exceeds the heat in the island of Borneo, or Sumatra, in the East-Indies, about as much as the heat in those places exceeds that of the Orkney islands, on the northern coast of Scotland; so that at sixty degrees of north latitude, on that planet, if its axis were perpendicular to the plane of its orbit, the heat would not exceed the greatest heat of our earth; and of course, vegetation might be carried on, and animals, of a species like ours, might subsist. And if Mercury's axis be supposed to have a like position, a circle round each of his poles, of about twenty degrees in diameter, would have the same temperature as the warmer regions of the earth; though in the hottest climate of this planet
water

water would continually boil, and most inflammatory substances be diffipated and destroyed.

But it is not at all necessary that the planets should be inhabited by animals like those upon the earth. That endless variety which we observe in every part of the creation, which comes under our inspection, plainly indicates that there may be beings, of whose nature and properties we can have no conception. We cannot suppose that the creative powers of the Deity have been employed only in peopling our little globe, which is but an atom in the universe: it is most probable, that there is an order of existences, in every planet, peculiar to its end and design, and that the Creator has adapted the inhabitants of each to their situation. Whether we shall ever be permitted to see the grand scheme of nature completely unfolded, is a matter beyond the reach of science to determine; but we have the highest reason to expect that our prospects will be further extended, and that our hopes of contemplating the more glorious works of creation will not be disappointed.

LETTER XXI.

OF THE ECLIPSES OF THE SUN AND MOON.

OF all the phænomena of the heavens, there are none that engage the attention of mankind more than eclipses of the sun and moon; and to those who are unacquainted with astronomical principles, nothing appears more extraordinary than the accuracy with which they can be predicted. In the early ages of antiquity, ere religion and science had enlightened the world, appearances of this kind were generally regarded as alarming deviations from the established laws of nature, and but few, even among philosophers themselves, were able to account for them. At length, when men began to apply themselves to observations, and the celestial motions were better understood, these phænomena were found to depend upon a regular cause, and to admit of a natural and easy solution.

It is to be observed, however, that most of the ancient calculations of eclipses must have been extremely defective; for as astronomy, in those times, was but imperfectly understood, all its dependent parts must have been subject to great

great inaccuracies. It is only since Newton has unfolded the theory of gravitation, and mechanics have been brought in to give their assistance to philosophy, that we have had a just idea of the construction of the universe; and though eclipses might have been computed independent of this knowledge, yet the calculations must have been far less exact than they are at present.

The accounts which are to be found in many of the early historians, concerning the prediction of eclipses, by Thales, Anaxagoras, and others, who lived long before the commencement of the Christian æra, are only to be understood of some of the most remarkable of these phenomena, which a gross calculation might determine sufficiently near the truth, to excite the admiration of an uninformed age. There are many elements that are used in the exact computation of solar eclipses in particular, which astronomers, in a less advanced state of the science, must have been totally unacquainted with; and as the moderns, by these means, have rendered their calculations far more accurate and precise, it affords a convincing proof, even to the most illiterate, that the principles from which such a perfect knowledge of the heavenly motions is derived, must be just and undeniable.

To enter into a popular explanation of all the principles of this doctrine, would be no easy task. I shall therefore only attempt to give you a general idea of the subject, and to shew you, without the embarrassment of calculations, the foundation upon which it depends. In the first place, then, it is to be observed, that all opaque or dark bodies, when they are exposed to the light of the sun, cast a shadow behind them in an opposite direction: and as the earth is a body of this kind, whose shadow extends over a large space, and to a great distance, it is plain that the moon, in passing through this space, must be deprived of her light, or suffer an eclipse; which is a Greek word that signifies dereliction.

And because the earth is spherical, the figure of the shadow would be cylindrical, if the earth and sun were of equal magnitudes: but if the earth were bigger than the sun, the figure of the shadow would be that of an inverted cone, growing thicker and thicker the farther it extended; so that in both these cases it would run out into infinite space, without ever terminating or coming to an end; and eclipse the superior planets Mars, Jupiter, and Saturn, when they were in opposition to the sun. But as this never happens, it is plain that the sun is bigger than the earth; and that the earth's shadow must be conical, and end in a point.

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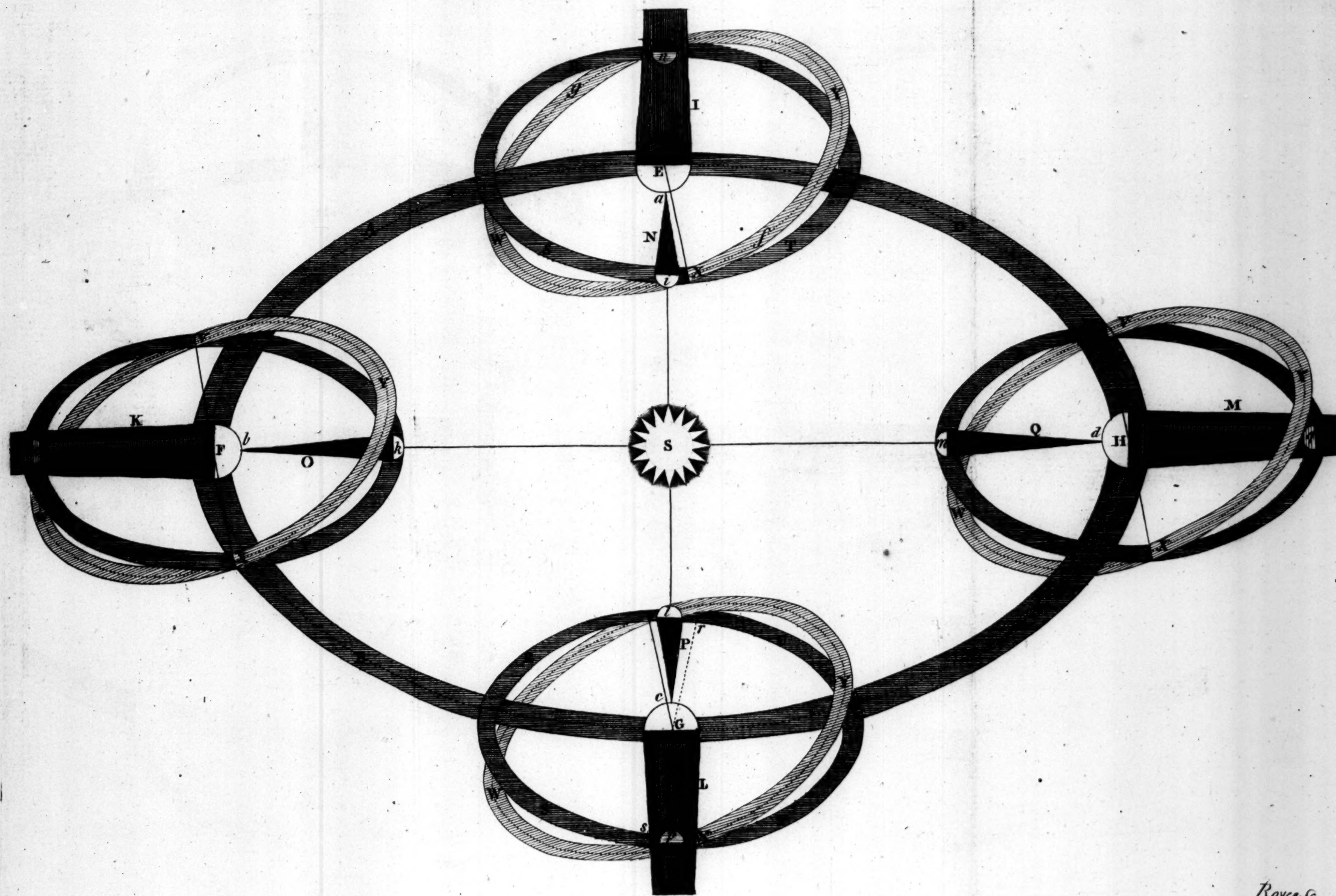
The figure of the moon's shadow is also that of a cone; and when it falls upon any part of the earth, the inhabitants of that part will be involved in darkness, and the sun will seem to them to be eclipsed as long as the shadow covers them. But as the moon is much less than the earth, and its shadow can extend over but a small portion of the earth's surface, there will be total darkness only in that space where the shadow falls; and in the circumjacent places, the inhabitants will see a greater or less part of the sun's disc obscured, according as they are nearer to or farther from the shadow: so that eclipses of the sun are always confined to particular places; but those of the moon may be observed from every part of the earth, when she is above the horizon at the time the eclipse happens.

If the sun and moon were of equal magnitudes, the moon's shadow would frequently extend over a portion of the earth's surface of more than 2000 miles broad; but this never happens: for, except in total eclipses of the sun, when the shadow falls very obliquely, it is seldom found to be 150 miles in breadth: so that from this circumstance, as well as from many others, it is sufficiently evident, that the moon must be much less than the sun. And since it is likewise found, from the time of the duration of many lunar eclipses, that the earth's shadow

is large enough to cover the moon, if her diameter were three times greater than it is, it also follows that the earth must be bigger than the moon.

From what has been said, it is plain that there can be no lunar eclipse but at the time of full moon, or when she is opposite to the sun; and that an eclipse of the sun can never happen but at the time of a new moon, or when she is in conjunction with that luminary: for it is only at those times that the earth and moon are in a straight line with the sun, or that the shadow of the one can fall upon the other. And since there is a new and full moon every month, it may be naturally enough imagined that there should be two eclipses in a month, one of the sun, and the other of the moon: but this is far from being the case; for there are but few eclipses in comparison to the number of new and full moons.

If, indeed, the plane of the moon's orbit were coincident with that of the earth's, the moon would then pass through the middle of the earth's shadow, and be eclipsed at every full: and, in like manner, the moon's shadow, falling upon some part of the earth, would occasion an eclipse of the sun at every change. But one half of the moon's orbit being elevated about five degrees and a third above the plane of the ecliptic, and the other half as much depressed
below



below it, the moon can never be in the same plane with the earth, but when she is in the nodes, or one of the two points where the orbits intersect each other. And therefore, as the moon may make a number of revolutions round the earth before a new or full moon takes place in one of those points, it is plain that there may be no eclipse, either of the sun or moon, in the space of several months.

When the nodes, or two points of intersection, are in a right line with the center of the sun at the time of a new moon, the moon's shadow will fall upon the earth, and occasion a solar eclipse; and if they have the same situation at the time of a full moon, the earth's shadow will fall upon the moon, and occasion a lunar eclipse. But when the sun and moon are more than seventeen degrees from either of the nodes at the time of conjunction, the moon is then generally too high or too low in her orbit for any part of her shadow to fall upon the earth. And when the sun is more than twelve degrees from either of the nodes, at the time of opposition, the moon is commonly too high or too low in her orbit to go through any part of the earth's shadow; so that in both these cases there will be no eclipse.

But when the moon is less than seventeen degrees from either of the nodes at the time of conjunction, a greater or less portion of her shadow will fall upon the earth as she is more

or less within this limit : and when she is less than twelve degrees from the node, at the time of opposition, she will go through a greater or less portion of the earth's shadow according to her situation. And as the sun commonly passes by the nodes but twice a year, and the moon's orbit contains 360 degrees, of which seventeen, the limit of solar eclipses, on either side of those points, and twelve the limit of lunar eclipses, are but small portions, it is easy to perceive that there must be many new and full moons without any eclipses.

The limits I have mentioned are subject to some variations ; but, as a scrupulous accuracy in a popular explanation of this kind would be tedious and unnecessary, I shall proceed to illustrate the general doctrine by a figure. For this purpose, let A B C D be the ecliptic, or the earth's path in the heavens ; R S T U a circle lying in the same plane, and V W X Y the moon's orbit ; one half of which X Y V is above the ecliptic, and the other half V W X below it. Then will the points V and X, where the two circles intersect each other, be the moon's nodes, and the right line X E V, drawn from the one to the other, through the earth's center, will be the line of the nodes ; which is carried in a position nearly parallel to itself, round the sun in a year.

Now it is plain from the figure, that if the moon moved round the earth in the circle R S T U, which is coincident with the plane of the ecliptic, her shadow would fall upon the earth every time she was in conjunction with the sun; and at every opposition she would go through the earth's shadow: so that in this case the sun would be eclipsed at every change, and the moon at every full. But as the moon moves in the circle V W X Y, which is inclined to the former in an angle of $5\frac{1}{3}$ degrees, there can be no eclipse but when she is in or near one of the nodes V or X, at the time of full or change: for in all other positions, she will be too much out of the plane of the ecliptic for her shadow to fall upon the earth, or for the earth's shadow to fall upon her.

When the moon is in conjunction with the sun at *i*, her shadow N must fall upon the earth at *a*, because she is then very near one of her nodes; and at her opposition *n* she must go thro' the earth's shadow I, because she is then near the other node. But in the time she goes once round the earth, according to the order of the letters X Y V W, the earth will have advanced forwards from E to *e*; and as the line of the nodes V E X, is always carried nearly parallel to itself, the moon at her next change will be at the point *f*, which is too high above the ecliptic for any part of her shadow to fall upon the earth.

And,

And, for the same reason, as the earth is still moving forward in its orbit, the moon, at her next opposition, will be at *g*; which is too far below the ecliptic for her to go through any part of the earth's shadow.

Again, when the earth has moved through a quarter of the ecliptic to *F*, and the moon is in conjunction with the sun *S*, she will not be at *k*, in a plane coincident with the ecliptic, but above it at *Y*, in the highest part of her orbit: and, in this situation, the point *b* of her shadow *O* will fall as far above the earth as possible. For the same reason, the moon, at her next opposition, will not be at *o*, but at *W*, in the lowest part of her orbit, in which situation she will be as far below the earth's shadow as possible: so that in both these cases the line of the nodes *V E X* will be about ninety degrees from the sun, and the two luminaries will be as far removed from the limits of eclipses as the nature of their orbits will admit.

When the earth has gone half round the ecliptic, from *E* to *G*, the line of the nodes *V G X*, is nearly directed towards the sun at *S*, and then the new moon *l* casts her shadow *P* upon the earth *G*; and the full moon *p* goes through the earth's shadow *L*, which brings on eclipses again, as when the earth was at *E*. And when the earth has gone three quarters round the ecliptic to *H*, the new and full moons fall not at *m* and *q*,
in

in a plane coincident with the ecliptic, but at W and Y, about $5\frac{1}{2}$ degrees below and above it: so that in this case the moon's shadow falls as far below the earth, and the earth's shadow as far below the moon, as possible; and they are as far removed from the limits of eclipses as when the earth was at F.

The point X, where the moon's orbit crosses the ecliptic, is called the Ascending Node, because the moon ascends from it above the ecliptic; and the opposite point of intersection V, is called the Descending Node, because the moon descends from it below the ecliptic. And when the moon is in the higher part of her orbit X Y V, she is said to have north latitude; and when she is in the lower part V W Y, she is said to have south latitude. So that from what has been said it appears, that when the earth is at E and G, the moon is about her nodes at new and full, and in her greatest north and south latitude at her quarters: but when the earth is at F or H, the moon is in her greatest north and south latitude at new and full, and in the nodes about her quarters.

If the line of the nodes were always carried parallel to itself round the sun, there would be just half a year between the conjunctions of the sun and nodes. But as the nodes shift backwards, or contrary to the earth's annual motion, about $19\frac{1}{4}$ degrees in a year, the same node will
come

come round to the sun about nineteen days sooner every year than upon the preceding one; so that from the time when the ascending node X passes by the sun, as seen from the earth at E, there will be only 173 days before the descending node passes by him. And consequently, at whatever time of the year we have eclipses about either of the nodes, we may be sure that in about 173 days afterwards we shall have eclipses about the other node.

And when at any time of the year the line of the nodes is in the situation V G X, at the same time next year it will be in the situation r G s; the ascending node X having gone backwards, or contrary to the order of the signs, from X to s, and the descending node from V to r, each about $19\frac{1}{3}$ degrees. At this rate, therefore, the nodes will shift through all the signs and degrees of the ecliptic in eighteen years and 225 days; and in this time there would always be a regular period of eclipses, if any complete number of lunations were finished without a fraction. But this never happens; for if both the sun and moon should set out together from a line of conjunction with either of the nodes, in any point of the ecliptic, the sun would go through eighteen annual revolutions and 222 degrees over, and the moon through 230 lunations and 85 degrees of the 231st, by the time the nodes came round to the same point of the ecliptic again;

again; and therefore, the sun would be then 138 degrees from the node, and the moon 85 degrees from the sun.

After the sun, moon, and nodes, however, have been once in a line of conjunction, they will return so nearly to the same state again in 223 mean lunations, or about eighteen years and ten days, as that the same node, which was in conjunction with the sun and moon at the beginning of the first of these lunations, will be within less than half a degree of a line of conjunction with the sun and moon again, when the last of these lunations is completed. And, therefore, in that time, there will be a regular period of eclipses, or returns of the same eclipses for many ages. But the falling back of the line of conjunction of the sun and moon, with respect to the line of the nodes, in every period, will at length exhaust it, and after that it will not return again in less than 12,492 years.

Another period for comparing and examining eclipses, which happen after long intervals of time, is that which consists of 6890 mean lunations, or about 557 years and 21 days; in which time the sun and node will meet again so nearly, as to be little more than eleven seconds distant: but it will not be the same eclipse that returns, as in the shorter period above-mentioned. These periods are said to have been discovered by the Chaldeans six or seven hundred
years

years before the birth of Christ; but M. Bailly, in his *Histoire de l'Astronomie Ancienne*, has endeavoured to shew, that the invention is of a much earlier date. He finds, from the testimonies of ancient authors, that these periods, as well as those of 19 and 600 years, that serve to shew the returns of the new moons, were known to the Arabs, Indians, Chinese, and Tartars, long before the sciences were cultivated in Greece. And as a knowledge of this kind could have only been obtained from a long series of observations, or a general and perfect acquaintance with the celestial motions, he thinks it probable, that these, as well as many other discoveries of equal importance, are due to the antediluvians, or the most ancient inhabitants of the earth.

But as this is a favourite hypothesis of M. Bailly's, in which I apprehend but few astronomers will agree with him, I shall leave the justification of his tenets to himself, and proceed to the illustration of our subject. In the first place, then, it will be necessary to give you some account of the different kinds of eclipses, and the causes that produce them. And here nothing more is requisite to be observed, than that every variety of this kind that can take place, either with respect to the sun or moon, is owing to the elliptical figure of their orbits, and the position they are in at the time the eclipse happens.

When

When the moon changes at her least distance from the earth, and is within the proper limits of the node, she will appear big enough to cover the whole solar disc, and those inhabitants of the earth where her shadow falls, will have the sun entirely hid from their sight for some minutes. But when the moon changes at her greatest distance from the earth, and is near enough to the node, her diameter will subtend a less angle than the sun's: and, on that account, her dark shadow must terminate in a point before it reaches the earth; and at the place over which it hangs, the sun's edge will appear like a luminous ring all round the body of the moon.

The former of these is called a total eclipse, and the latter an annular one. And as the moon's apparent diameter when largest, exceeds the sun's when least, by only about $1\frac{1}{2}$ minutes of a degree; in the greatest eclipse of the sun that can happen at any time and place, the total darkness will continue no longer than whilst the moon is going $1\frac{1}{2}$ minute in her orbit from the sun; which she describes in a little more than three minutes of an hour. But when the change happens within seventeen degrees of the node, and the moon is at her mean distance from the earth, the point of her shadow will just reach the earth, and on the small spot where it falls, the darkness can be only of a moment's continuance.

A total

A total eclipse of the sun is a very curious spectacle. Clavius, who observed the one which happened on the 21st of August, at Coimbra, observes, that the obscurity was greater, or at least more striking and sensible, than that of the night. It was so dark for some time, that he could scarcely see his hand; some of the largest stars made their appearance for about a minute or two, and the birds were so terrified that they fell to the ground. These eclipses, however, happen but seldom at any particular place; and annular ones are much less common: the last remarkable one of this kind was that of the 1st of April 1764, which was seen at Rennes, Calais, and Pello in Lapland.

Dionysius of Halicarnassus mentions two total eclipses of the sun that happened, one at the birth of Romulus, and the other at his death, in each of which the obscurity was as great as in the middle of the darkest night. But this account, like that of the prodigies which were seen at the death of Cæsar, deserves but little credit. In ancient times, every great event was said to have been accompanied with comets or other portentous appearances, and eclipses of the sun in particular were always regarded as calamitous omens, presaging the death of Kings, or some illustrious character. This superstition is frequently alluded to by the Poets, and is the foundation

Fig. 1.

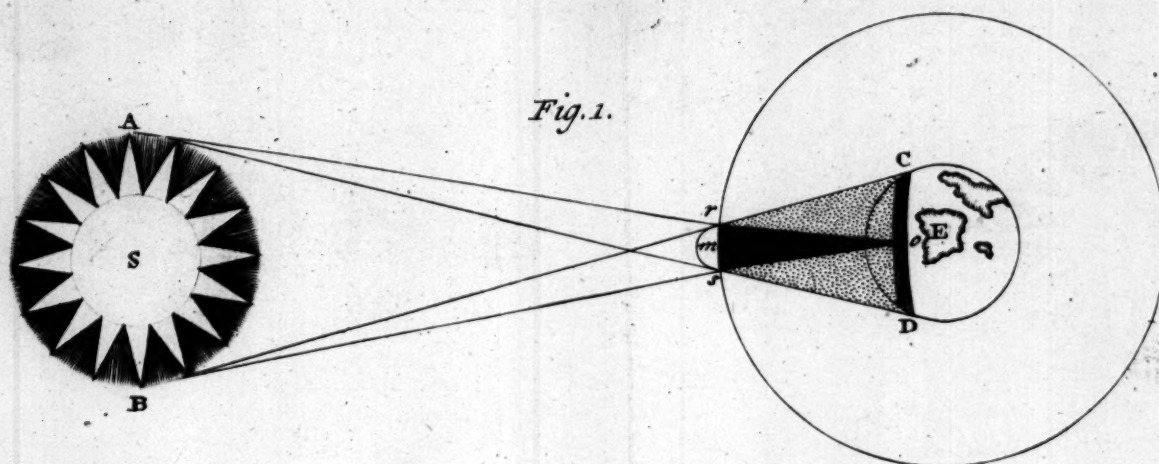


Fig. 2.

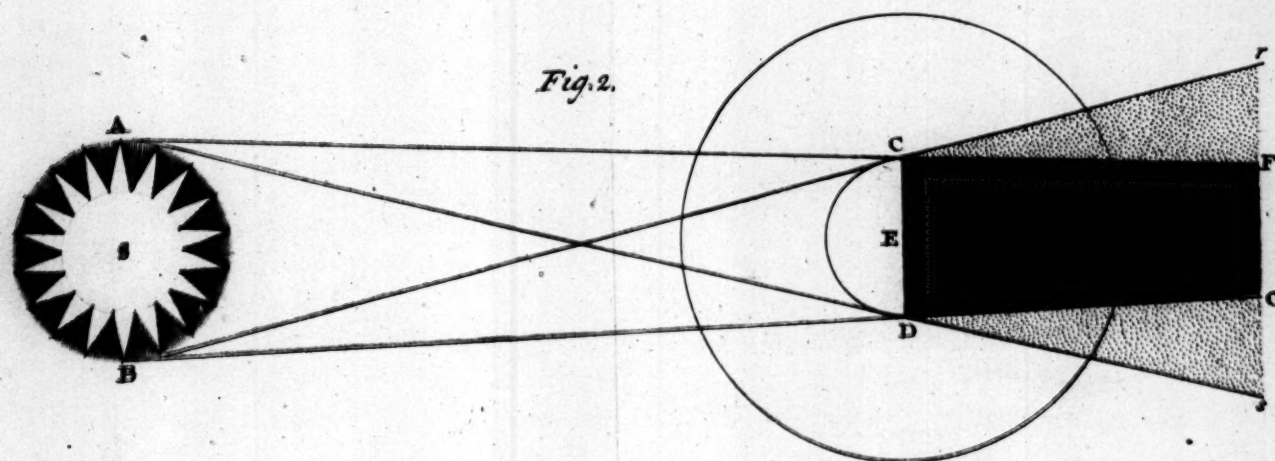
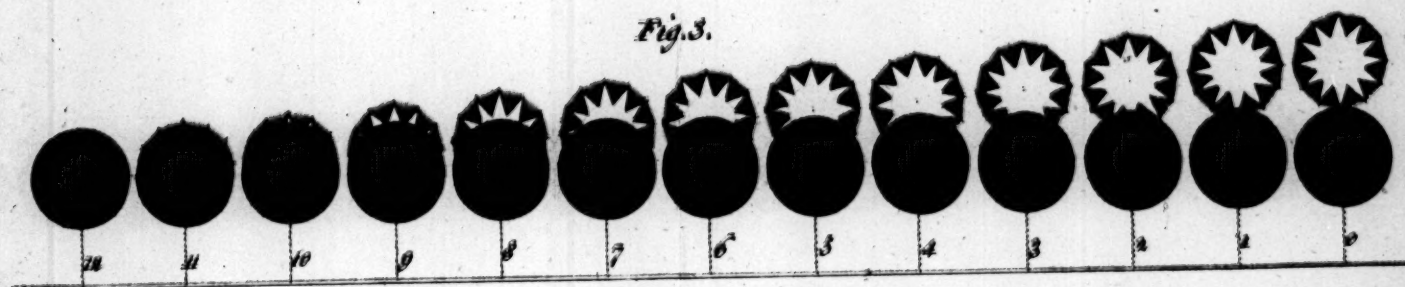


Fig. 3.



foundation of one of the noblest similes in the *Paradise Lost*.

—————“ As when the sun new risen
Looks through the horizontal misty air
Shorn of his beams, or from behind the moon
In dim eclipse disastrous twilight sheds
On half the nations, and with fear of change
Perplexes monarchs : darkned so, yet shone
Above them all th’ Arch-Angel.”

In China, where astronomy is made subservient to the interest of the state, they have particular ceremonies appropriated to those days on which eclipses are to take place, and according to the accounts of the missionaries, both the prince and the people are scrupulously exact in the observance of them. The chief of the Tribunal of the Mathematics is here a grand, but dangerous appointment ; for, under the reign of the emperor Chou-kang, the two principal astronomers Ho and Hi, were condemned to death, on account of their omitting, through negligence and intoxication, to announce the precise time of an eclipse of the sun. This eclipse, which happened 2169 years before Christ, and a remarkable conjunction of four of the planets, which their annals affirm to have taken place at a still earlier period, are thought, by many astronomers who have examined the subject, to be strong proofs of the authenticity of the Chinese chronology.

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But

Pl. XIX.
fig. 1.

But to return to our subject.—Besides the dark shadow of the moon already mentioned, there is another fainter one, called the Penumbra, which always accompanies a solar eclipse, and takes place upon those parts of the earth which are only partially deprived of the sun's rays. For let S be the sun, E the earth, and m the moon; then if two right lines be drawn from A and B to touch the body of the moon in r and s , they will form the cone $r o s$, which is the figure of her dark shadow, as it falls upon the earth at o ; and two other lines, drawn through the same points transversely, will shew the limits of the penumbra, or faint shadow $C r s D$; in every part of which space there is more or less light, according as it is farther from, or nearer to the center O .

And as the moon moves eastward over the sun's disc, the dark shadow describes the path $C D$, and all the inhabitants living within that tract will have the sun successively and totally eclipsed; whilst those who are at some distance from it, will have a partial eclipse, according as they are, more or less, within the circle of the penumbra $C r s D$. So that when the penumbra first touches the earth the general eclipse begins, and when it leaves the earth the eclipse ends, the whole duration, at a mean rate, being about five hours and fifty minutes.

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The earth's dark shadow $FCDG$, is also encompassed by a penumbra, in the same manner as the moon's, which is faint towards the edges C and D , and more obscure towards C and D ; and this is the reason why it is so difficult to observe exactly either the beginning or end of a lunar eclipse, even with a good telescope; for the earth's shadow is so faint and ill-defined about the edges, that when the moon is either just touching or leaving it, the obscuration of her limb is scarcely sensible; and therefore the best observers may be subject to a mistake of several seconds. But both the beginning and end of solar eclipses are visibly instantaneous; for the moment the edge of the moon's disc touches the sun's, his roundness seems a little broken on that part; and the moment she leaves it, he appears perfectly round again.

The moon, when totally eclipsed, is seldom invisible, but generally appears of a dusky colour, resembling tarnished copper, which some have thought to be owing to her own native light; but the true cause of this appearance is the scattered beams of the sun, which are so bent into the earth's shadow, in their passage through the atmosphere, as to afford us a sufficient quantity of light to render the moon visible. There have, however, been eclipses of the moon, when in that part of her orbit nearest the earth, in which she has entirely disappeared; but these instances are

very rare. Hevelius mentions one of this kind, which happened on the 25th of April, 1642, when he was not able to distinguish the place of the moon, even with a good telescope, although the sky was sufficiently clear for him to see stars of the fifth magnitude.

From what has been said, it is also plain, that there may be a total eclipse of the moon, although she be not exactly in either of the nodes at the time the eclipse happens; for as the diameter of the earth's shadow is much greater than that of the moon, it is plain that she may be wholly involved in the dark cone without passing directly through its axis. The moon may likewise be at such a distance from the node, that only a part of her body can enter the earth's shadow, and then we shall have a partial eclipse of the moon, which will be greater or less, according to her situation. But when it happens that the full moon takes place exactly in one of the nodes, then the axis of the earth's shadow will pass through the center of the moon, and it will be a total and central eclipse.

Pl XIX.
fig. 3.

The diameters of the sun and moon are supposed to be divided into twelve equal parts, and an eclipse is said to be of so many digits, according to the number of those parts which are involved in darkness. It must also be observed, that an eclipse of the moon always begins on her eastern side, and goes off on her western

western one; and that an eclipse of the sun begins on his western side, and goes off on his eastern one. And all that the moon is eclipsed above twelve digits, shows how far the shadow of the earth extends over her body, on that edge to which she is nearest at the middle of the eclipse.

Eclipses of the sun are more frequent than those of the moon, because his ecliptic limits are greater; and yet we have more visible eclipses of the moon than of the sun; which is owing to their being seen from all parts of the earth, where the moon is above the horizon at the time the eclipse happens; whilst those of the sun can only be observed on that small portion of the hemisphere on which the moon's shadow falls. The greatest number of eclipses, of both luminaries, which can happen in a year, is seven, and the least two; but the most usual number is four; and it is very rare that there are more than six, one half of which are generally invisible at any particular place.

These are the principal particulars relating to the doctrine of eclipses, that admit of a familiar illustration, and if they be properly considered, it will not be difficult to conceive how astronomers are able to foretell the exact time when any phenomenon of this kind will happen. For as an eclipse can only take place at the time of a new or full moon, the chief requisites are to

determine the number of mean conjunctions and oppositions that will arrive in every year, and the true places of the sun and moon in their orbits at each of those times. And if from this it appears, that the two luminaries are within the proper limits of the node, there will be an eclipse, or otherwise not, agreeable to what has been already observed upon this subject.

But in order to facilitate these operations, we have astronomical tables ready computed from the theory of gravitation, by which the places of the heavenly bodies, and every other necessary particular, may be easily found for any given instant of time. Dr. Halley has also given a catalogue of all the eclipses that took place from the year 1701 to 1718, which the author of *L'Art de verifier les Dates*, and others, have continued up to the year 1800; so that by means of the period of eighteen years, in which there is found to be nearly a regular return of the same eclipses, it is easy to institute a calculation that will determine to a great degree of precision the times in which they will happen.

This method, however, is not strictly scientific; and there are, besides, many other elements which are employed in calculating the quantity and duration of eclipses, which, as you are unacquainted with the higher parts of mathematics, it is scarcely possible to explain in a clear and satisfactory manner. If what has
been

been said should lead you to wish for a farther acquaintance with this doctrine, you will find it amply treated of by M. de la Lande, Dr. Long, and others; but these authors cannot be read, to any advantage, till you have obtained a previous knowledge of many other branches of science.

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LETTER XXII.

OF THE NEW PLANET, AND OTHER DISCOVERIES.

IT is a general and immemorial tradition, which is countenanced both by sacred and profane history, that prodigious changes and revolutions have taken place in our globe since its first formation : and the bare inspection of the earth gives great weight to this opinion. We can perceive in many instances, that the waters have successively covered and abandoned the beds that contained them. The vegetables and fishes of India, which are found in the petrefactions of Europe ; and the number of shells, and other marine productions, discovered in ranges of mountains very remote from the sea, can be accounted for upon no other principle. This was a doctrine which was taught both by Pythagoras and his followers ; and Ovid, in explaining the tenets of that sect, speaks in the

name

name of all the Oriental Philosophers, when he says,

“ The face of places, and their forms, decay ;
And what was solid earth converts to sea ;
Seas, in their turn, retreating from the shore,
Make solid lands what ocean was before ;
And far from strands are shells of fishes found ;
And rusty anchors fix'd on mountain ground :
And what were fields before, now mark'd and worn
By falling floods, from hills to vallies turn :
And crumbling still descend to level lands ;
And lakes, and trembling bogs, are barren sands :
And the parch'd desert floats in streams unknown,
Wondering to drink of waters not her own.”

To these testimonies, which seem consonant both with history and experience, may be added another still more singular ; which is that of the ancient Egyptians, who maintained that the sun, in former ages, had risen in the west and set in the east. It was indeed a tradition as obscure as their hieroglyphics ; and Herodotus, Plato, Diogenes Laertius, and Plutarch, who all mention this revolution, must be considered as authors by far too modern to deserve much credit with regard to such antiquities. They are, however, so many remaining witnesses that this opinion once prevailed ; and other discoveries make it probable, that the idea, extravagant as it may seem, was not altogether without foundation.

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The best modern astronomers are now generally agreed, that the angle which the ecliptic makes with the equator is continually decreasing, at the rate of about one minute in a hundred years; and therefore, if the earth continues in existence, and this diminution proceeds, the two circles, in about 140,000 years, will coincide, and the sun, moving in or near the equator, will make equal days and nights all over the globe for many ages. This enormous period, however, may never be completed; and to seek for a solution of the Egyptian ænigma, as some writers have done, from these principles, would be to invalidate the truth of revelation, and the most authentic records of sacred history. A revolution of this kind, sufficient to reverse the four cardinal points of the compass, could not have been accomplished in less than two millions of years; and this is giving a length of duration to the world, that but few will admit.

We are told by Diodorus Siculus, that the philosophers of Babylon, at the time of Alexander's entry into that city, reckoned 403,000 years from the beginning of their astronomical observations. And upon a supposition that the ecliptic was first perpendicular to the equator, and afterwards began to approach towards it, according to the rate above-mentioned, this period very nearly agrees with the diminution of
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the angle, which, in that time, had taken place, and reduced the obliquity to 23 degrees and a half. But from this it is not to be inferred, that the Chaldean astronomers had actually observed the celestial motions for so many ages. It is the custom of all conquered nations to boast of their origin, and to endeavour to recover by their antiquity the glory they have lost by their weakness. They were most probably acquainted with the varying obliquity of the ecliptic, and having discovered this epocha by calculation, pretended that it was derived from real observations.

Some, however, are of a contrary opinion; and from the uncertainty of ancient observations, are disposed to believe, that the obliquity of the ecliptic has been always the same. But in this they appear to be mistaken; for besides the apparent decrease of this angle, which has been observed by almost every astronomer since the time of Hipparchus, the variation of latitude in the fixed stars is such as could arise from no other cause. Ptolemy tells us expressly that he determined the obliquity, for several years together, to be 23 degrees 51 minutes, and it is now known to be 23 degrees 28 minutes, which appears to be too great a difference to be attributed to any defect in his observations. But independent of ancient testimonies, the attention which has been bestowed upon this subject for near a century past, has enabled us to decide with

with certainty that the diminution is real, and according to a certain law.

M. Euler has endeavoured to shew, that this effect is produced by the attraction of the planets; but as the principles upon which he proceeds are too abstruse and complicated to be explained in a popular manner, I shall not attempt to illustrate them; but proceed to give you some account of another discovery, no less important than the former. Hipparchus, in comparing his observations with those of Timocharis, which had been made at Alexandria about a century before, first perceived that the stars changed their positions, and appeared to have a slow motion from west to east with regard to the equinoctial points.

This change of the stars in longitude, which has now become sufficiently apparent, is owing to a small retrograde motion of the equinoctial points, of about 50 seconds in a year, which is occasioned by the attraction of the sun and moon upon the protuberant matter about the equator, in nearly the same manner as the action of the sun produces the retrograde motion of the nodes of the moon. The same cause also occasions a small deviation in the parallelism of the earth's axis, by which it is continually directed towards different points in the heavens, and makes a complete revolution round the axis of the ecliptic in about 25,920 years.

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The former of these motions is called the precession of the equinoxes, and the latter the nutation of the earth's axis. And in consequence of this shifting of the equinoctial points, an alteration has taken place in the signs of the ecliptic; those stars, which in the infancy of astronomy were in Aries, being now got into Taurus; those of Taurus into Gemini, &c. So that the stars which rose and set at any particular season of the year, in the times of Hesiod, Eudoxus, Virgil, &c. will not at present answer to their descriptions.

But of all the discoveries in this science, none will be thought more singular than that which has lately been made by Mr. Herschel, Astronomer to his Majesty at Windsor; who, as he was pursuing a design he had formed of observing, with telescopes of his own construction, every part of the heavens, discovered, in the neighbourhood of η Geminorum, a star, which, in magnitude and situation, differed considerably from any that he had before observed, or found described in the catalogues.

This induced him to consider it with particular attention, and, by continuing his observations, he found that it could not belong to any class of new or temporary stars which had been seen at particular times by preceding astronomers: for by measuring its motion by a micrometer, he found it to move regularly, according
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to the order of the signs; that its apparent diameter was on the increase, and that it declined but little from the ecliptic; which circumstances at first led him to conclude, that it must be some comet belonging to our system, whose remote situation had hitherto prevented it from being observed.

As a comet, however, it seemed particularly singular, since no tail, or any hairy or nebulous appearance, could be perceived, by which those bodies are always distinguished from the rest of the system; on the contrary, it was found to shine with a faint steady light, something paler and more faint than Jupiter, and appeared about four seconds in diameter. Its differing so materially from other comets was ascribed to its immense distance from the sun, at which the heat was not sufficient to rarify the gross atmosphere, so as to extend it far enough from the body of the comet for it to become visible.

A discovery of this nature soon engaged the attention of the most eminent astronomers of Europe, and many observations were accordingly made at different times and places. Amongst which, those of M. Lexell, of Peterfbourg, appear to have been of particular service, in determining the real nature and class of celestial bodies to which this phenomenon belongs. These observations, compared with those of other eminent astronomers, sufficiently prove, that this star is a PRIMARY PLANET, belonging to the solar system,

system, which, till the 13th of March 1781, when it was first seen by Mr. Herschel, had escaped the observation of every other astronomer, both ancient and modern.

From a series of observations, continued for eight months, during which time this planet was both in opposition and conjunction, and had moved through a part of its orbit of more than six degrees, M. de la Lande calculated its course for 1782, and found that its distance from the sun is near nineteen times greater than that of the earth; that its magnitude is about eighty-nine times greater than the earth's; and that it revolves round the sun in an orbit, which is nearly circular, in about eighty-two years.

The apparent diameter of this planet being but about four seconds, it can seldom be seen very plainly by the naked eye, but may easily be discovered in a clear night, when above the horizon, by a good telescope; its situation, with respect to the fixed stars, being previously known. Whether it be attended by any satellites has not yet been discovered; it should seem probable, however, as the superior planets, Jupiter and Saturn, have several moons revolving round them, that this also, which is much farther removed from the source of light and heat, should have the same kind of attendants, but which, on account of their immense distance and smallness, are totally invisible.

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As a mark of respect to his present Majesty, and to convey an idea to posterity of the time and place of the discovery, Mr. Herschel has distinguished this planet by the name of the *Georgium Sidus*, following the example of Galileo, who, in honour of his patrons, the illustrious House of Medici, called the Satellites of Jupiter, which he first discovered, the *Medicean Stars*.

This discovery, which at first appears more curious than useful, may yet be of great service to astronomy; the circumstance of a primary planet having been unobserved for so many ages, will naturally lead astronomers to examine, with greater accuracy, those small stars which have hitherto been generally neglected, or only considered as of use in determining the position of the planets. And these observations may produce many new discoveries in the celestial regions, by which our knowledge of the heavenly bodies, and of the immutable laws that govern the universe, will become much more extended; which is the great object of the science, and the source from whence we may expect to derive such consequences as are of practical application, and the most useful to mankind.

Having thus endeavoured to give you, in as familiar a manner as possible, a general idea of the most interesting parts of astronomy, I shall conclude

finish the subject with Sir Isaac Newton's account of the Deity, given at the latter end of his *Principia*, which he considered as the most proper conclusion for a work that consists chiefly in an attempt to investigate the laws by which this great Being conducts his operations, and regulates the machine of the universe over which he presides.

“Seven primary planets revolve about the sun, in circles concentric with him, with motions directed towards the same parts, and almost in the same plane. Ten moons revolve about the Earth, Jupiter and Saturn, in circles concentric with them, with the same direction of motion, and nearly in the planes of the orbits of those planets. But it is not to be conceived, that mere mechanical causes could give birth to so many regular motions, since the comets range freely over all parts of the heavens in very eccentric orbits: by which kind of motion they pass easily through the orbs of the planets, and with great rapidity; and in their aphelions, where they move the slowest, and continue the longest, they recede to the greatest distances from each other, and thence suffer the least disturbance from their mutual attractions.

“This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being. And if the fixed stars are the centers of

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similar

similar systems, these, being formed by the like wise counsels, must be all subject to the dominion of One; especially, since the light of the fixed stars is of the same nature with the light of the sun, and from every system light passes into all the other systems. And lest the systems of the fixed stars should, by their gravity, fall on each other mutually, he has placed them at immense distances from each other.

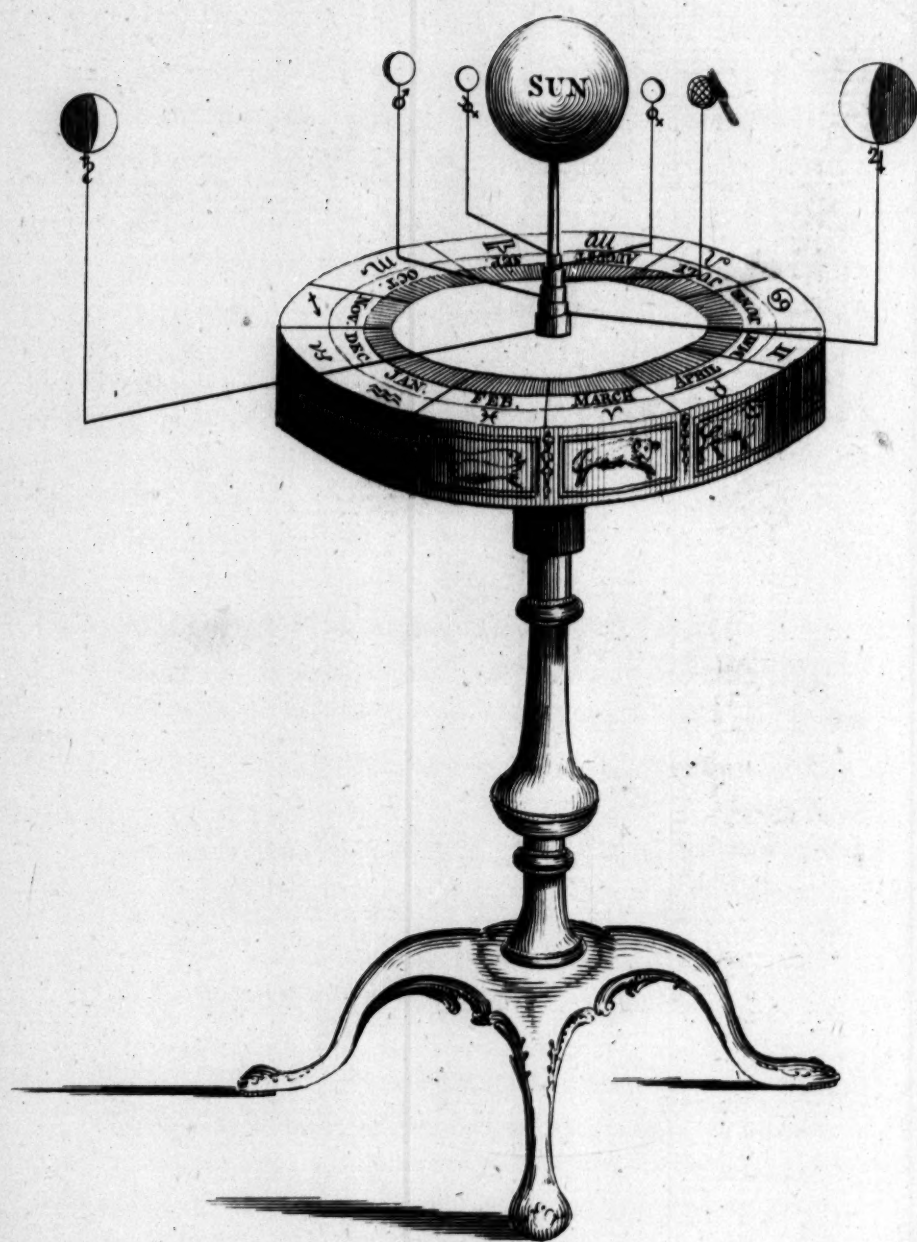
“This Being governs all things, not as the Soul of the World, but as Lord over all; and, on account of his dominion, he is wont to be called Lord God, or Universal Ruler. For God is a relative word, and has respect to servants; and Deity is the dominion of God, not over his own body, as those imagine who fancy him to be the Soul of the World, but over servants. The Supreme God is a Being eternal, infinite and absolutely perfect; but a Being, however perfect, without dominion, cannot be said to be Lord God: for we say, my God, your God, the God of Israel, the God of Gods; my Eternal, your Eternal, the Eternal of Israel, the Eternal of Gods: but we do not say, my Infinite, or my Perfect; these are titles which have no respect to servants. The word God usually signifies Lord; but every Lord is not a God. It is the dominion of a spiritual Being which constitutes a God; a true, supreme or imaginary dominion, makes a true, supreme or imaginary God.
And

And from his true dominion it follows, that the true God is a living, intelligent, and powerful Being; and from his other perfections, that he is supreme or most perfect. He is eternal and infinite, omnipotent and omniscient; that is, his duration reaches from eternity to eternity, his presence from infinity to infinity; he governs all things, and knows all things that are or can be done. He is not eternity or infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures for ever, and is every where present; and by existing always and every where, constitutes duration and space. Since every particle of space is always, and every indivisible moment of duration is every where, certainly the Maker and Lord of all things cannot be never and no where. Every soul that has perception is, though in different times, and in different organs of sense and motion, still the same indivisible person. There are given successive parts in duration, and co-existent parts in space, but neither the one nor the other in the person of a man, or his thinking principle; and much less can they be found in the thinking substance of God. Every man, so far as he is a thing that has perception, is one and the same man during his whole life, in all and each of his organs of sense. God is one and the same God, always and every where. He is omnipresent, not virtually only, but also substan-

tially; for virtue cannot subsist without substance. In him are all things contained and moved; yet neither affects the other: God suffers nothing from the motion of bodies; bodies find no resistance from the omnipresence of God. It is allowed by all, that the Supreme God exists necessarily, and by the same necessity he exists always and every where. Hence also he is all similar, all eye, all ear, all brain, all arm, all power to perceive, to understand, and to act; but in a manner not at all human, in a manner not at all corporeal, in a manner utterly unknown to us. As a blind man has no idea of colours, so have we no idea of the manner by which the all-wise God perceives and understands all things. He is utterly void of all body and bodily figure, and can therefore neither be seen, nor heard, nor touched; nor ought he to be worshipped under the representation of any corporeal thing. We have ideas of his attributes, but what the real substance of any thing is, we know not. In bodies we see only their figures and colours, we hear only the sounds, we touch only their outward surfaces, we smell only the odours, and taste the favours, but their inward substances are not to be known, either by our senses, or by any reflex act of our minds; much less, then, have we any idea of the substance of God. We know him only by his properties and attributes, by his most
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wise and excellent contrivances of things, and final causes; we admire him for his perfections, but we reverence and adore him on account of his dominion. For we adore him as his servants; and a God without dominion, providence, and final causes, is nothing else but Fate and Nature. Blind metaphysical necessity, which is certainly the same always and every where, could produce no variety or change. All that diversity of natural things which we find, suited to different times and places, could arise from nothing but the ideas and will of a Being necessarily existing. But, by way of allegory, God is said to see, to love, to rejoice, to fight, &c. for all our notions of God are taken from the ways of mankind, by a certain similitude, which, though not perfect, has some likeness however.

“ And thus much concerning God; to discourse of whom, from the appearances of things, certainly belongs to Natural Philosophy.”



A PLANETARIUM,
Shewing the various Phænomena of the
 Copernican System.

AN EXPLANATION OF THE PRINCIPAL
TERMS MADE USE OF IN ASTRONOMY.

A

ABERRATION, an apparent change of place in the fixed stars, which arises from the motion of the earth combined with the motion of light.

ACHERNAR, a fixed star of the first magnitude in the constellation Eridanus.

ÆRAS, certain periods of time from whence Chronologers and Astronomers begin their computations.

ALDEBARAN, a fixed star of the first magnitude, situated in the head of the constellation Taurus, and from thence by some called the Bull's Eye.

ALGENEB, a fixed star of the second magnitude in the right side of Perseus.

ALGOL, or Medusa's Head, a fixed star of the third magnitude in the constellation Perseus.

ALLIOTH, the name of a fixed star in the tail of the great Bear.

ALMACANTERS, certain imaginary circles, which, in every position of the globe, are supposed to be drawn parallel to the horizon.

ALPHETA, or Lucida Corona, the name of a fixed star of the second magnitude, in the constellation called the Northern Crown.

ALTAR, a southern constellation consisting of nine stars,

ALTITUDE, the height of the sun, moon, or stars, above the horizon, reckoned upon a vertical circle, in degrees, minutes, &c.

AMPHISCII, a name given to the inhabitants of the Torrid Zone, on account of their shadows falling at one time of the year towards the north, and at another time towards the south.

AMPLITUDE, an arc of the horizon contained between the east or west point of the heavens, and the center of the sun or a star, at the time of its rising or setting.

ANDROMEDA, a northern constellation consisting of sixty-six stars.

ANGLE, the inclination or opening of two lines meeting in a point.

ANOMALY, (True) the distance of a planet in signs, degrees, &c. from that point of its orbit which is the farthest from the sun.

ANOMALY, (Mean) is that which would take place if the planet moved uniformly in the circumference of a circle.

ANSER, the Goose, a northern constellation consisting of ten stars.

ANSER AMERICANUS, the American Goose, a southern constellation consisting of nine stars.

ANTARES, a fixed star of the first magnitude in the constellation Scorpio.

ANTÆCI, a name given to those inhabitants of the earth, who live under the same meridian, and at equal distances from the equator, but on opposite sides of it.

ANTECEDENTIA, a motion of any of the heavenly bodies which is contrary to the order of the signs, as from Aries towards Pisces, &c.

ANTINOUS, a northern constellation consisting of thirty-four stars.

ANTI-

ANTIPODES, those inhabitants of the earth who live diametrically opposite to each other, or walk feet to feet.

APIS, the Bee, a southern constellation composed of four stars.

APHELION, that point in the orbit of a planet in which it is at its greatest distance from the sun.

APOGÆON, that point in the orbit of a planet in which it is at its greatest distance from the earth.

APSIDES, two points in the orbit of a planet in which it is at its greatest and least distance from the sun: The line joining those points is called the line of the Ap-sides.

AQUARIUS, a zodiacal constellation which contains ninety-three stars.

AQUILA, or Vultur Volans, a constellation in the northern hemisphere, consisting of twelve stars.

ARCTURUS, a fixed star of the first magnitude, situated in the skirts of the constellation Bootes.

ARGO, the Ship, a southern constellation consisting of forty-eight stars.

ARMILLARY SPHERE, an instrument composed of the principal circles which are usually drawn upon an artificial globe.

ARIES, the Ram, a zodiacal constellation consisting of forty-six stars, into which the sun enters about the 20th of March, or the beginning of the spring quarter.

ASCII, the inhabitants of the torrid zone; so called, because the sun being twice a year in their zenith, their bodies at those times cast no shadow.

ASCENSIONAL DIFFERENCE, an arc of the equinoctial contained between that point of it which rises with the sun, moon or star, and that which comes to the meridian with them; or it is the time the sun rises or sets before or after six o'clock.

ATMO-

ATMOSPHERE, that collection of vapours, or body of air, which surrounds or encompasses the earth.

ATTRACTION, a property of matter, by which bodies are made to approach towards each other, without any sensible agent either drawing or impelling them.

AURORA, the morning twilight, which begins to appear when the sun is about eighteen degrees below the horizon.

AURIGA, a northern constellation containing forty-six stars.

AXIS of the earth, an imaginary line passing through the center from one pole to the other.

AZIMUTHS, great circles which pass through the zenith and nadir, and are perpendicular to the horizon.—The Azimuth of any celestial object is an arc of the horizon, contained between the east or west point of the heavens, and a vertical circle passing through the center of that object.

B.

BASILICUS, or Cor Leonis, a fixed star of the first magnitude in the constellation Leo.

BEARS, two constellations in the northern hemisphere, called Ursa Major and Ursa Minor; the first consisting of one hundred and five stars, and the second of twelve: The north pole star is in the tail of the little Bear.

BERENICE'S HAIR, a northern constellation consisting of twenty-four stars.

BETELGUESE, a star of the first magnitude in the east shoulder of Orion.

BISSEXTILE, or Leap-Year; so called by the Romans, on account of their reckoning the 6th day of the calends of March twice over.

BOOTES,

BOOTES, a northern constellation consisting of fifty-three stars, one of which, *Arcturus*, in the skirts of his coat, is of the first magnitude.

C.

CAMELOPARDALUS, a northern constellation composed of twenty-three stars.

CANCER, the Crab, one of the signs of the ecliptic, consisting of seventy-five stars, into which the sun enters about the 21st of June, or upon our longest day,

CANIS MAJOR, and **CANIS MINOR**, the Great and Little Dog, two constellations in the southern hemisphere, the first consisting of twenty-nine stars, and the second of fourteen,

CANOPUS, a star of the first magnitude in the constellation *Argo*,

CAPELLA, a fixed star of the first magnitude in the left shoulder of the constellation *Auriga*.

CAPRICORNUS, the Goat, one of the signs of the ecliptic, consisting of fifty-eight stars; into which the sun enters about the 21st of December, or upon our shortest day.

CARDINAL POINTS, the east, west, north and south points of the compass.

CARDINAL POINTS of the ecliptic, the first points of the signs *Aries*, *Cancer*, *Libra* and *Capricorn*.

CASSIOPEIA, a constellation in the northern hemisphere consisting of fifty-two stars.

CAUDA LUCIDA, the Lion's Tail, a fixed star of the first magnitude in the constellation *Virgo*.

CENTAUR, a southern constellation consisting of thirty-six stars.

CENTRI-

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CENTRIFUGAL FORCE, that force by which any revolving body endeavours to fly off from the center of motion in a tangent to the circle which it describes.

CENTRIPETAL FORCE, that force by which any revolving body is made to tend towards the center of its orbit.

CEPHEUS, a constellation in the northern hemisphere consisting of forty stars.

CERBERUS, a northern constellation composed of nine stars.

CETUS, the Whale, a southern constellation which contains eighty stars.

CHARLES'S OAK, a southern constellation composed of thirteen stars.

CHARLES'S WAIN, seven remarkable stars in *Ursa Major*, or the Great Bear.

CHAMELION, a southern constellation composed of ten stars.

CHRISTALLINE HEAVENS, in the Ptolemaic system, two solid orbs, by means of which the ancients attempted to account for the apparent motion of the fixed stars.

COMETS, certain erratic bodies belonging to our system, which move round the sun in very eccentric orbits, and are principally distinguished from the planets by their tails, or some hairy or nebulous appearance.

COR CAROLI, Charles's Heart, an extra constellated star in the northern hemisphere, situated between *Coma Berenicens* and *Ursa Major*, so called in honour of King Charles the Second; some make it a constellation consisting of three stars.

CORONA BOREALIS, the Northern Crown, a constellation in the northern hemisphere consisting of eleven stars.

CORONA MERIDIONALIS, the Southern Crown, a southern constellation composed of twelve stars.

COLURES, two great circles, or meridians, one of which passes through the solstitial points Cancer and Capricorn, and the other through the equinoctial points Aries and Libra.

CONJUNCTION, is when two stars, seen from the sun or the earth, appear in the same point of the heavens, or answer to the same degree of the ecliptic.

CONSTELLATION, a number of stars lying in the neighbourhood of each other, which Astronomers, for the sake of remembering with more ease, suppose to be circumscribed by the outlines of some animal, or other figure.

COSMICAL rising, or setting of the stars, is when they rise with the sun in the morning, or set with him in the evening.

CONSEQUENTIA, a motion of the planets according to the order of the signs; as from Aries towards Taurus, &c.

CORVUS, the Crow, a southern constellation consisting of eight stars.

CRATER, the Cup, a southern constellation composed of eleven stars.

CROSSIERS, four stars in the form of a cross, which are of use to sailors in finding the south pole.

CULMINATING, a term applied to the sun or a star when it comes to the meridian of any place.

CYCLE of the moon, a revolution of nineteen years, in which time the conjunctions and lunar aspects are nearly the same as they were nineteen years before.

CYGNUS, the Swan, a constellation in the northern hemisphere consisting of seventy-three stars.

DAY,

D.

DAY, (Natural,) that portion of time in which the earth completes an entire revolution upon its axis.

DAY, (Artificial,) the time between the sun's rising and setting; to which is opposed night, or the time between his setting and rising.

DAY, (Astronomical,) the time between two successive transits of the sun's center over the same meridian; which always begins and ends at noon.

DECLINATION of the sun, moon or stars, is their distance north or south from the equator, reckoned in degrees, minutes, &c. upon a circle which is perpendicular to it.

DECHOTOMIZED, a term applied to the moon when she is in her quadratures, and appears only half illuminated.

DEGREE, the 360th part of a circle, or the 30th part of a sign.

DELPHINUS, the Dolphin, a constellation in the northern hemisphere consisting of eighteen stars.

DIRECT, a planet is said to be direct, when it moves according to the order of the signs; as from Aries towards Taurus, &c.

DISC of the sun, or moon, is its round face, which, on account of the great distance of the object, appears flat, or like a plane surface.

DIGIT, in Astronomy, the 12th part of the sun's diameter, which is often used in the calculation of eclipses.

DIURNAL, of or belonging to the day; thus, the diurnal motions of the planets, are the spaces they move through in a day.

DISTANCE, in Astronomy, is sometimes denoted by a straight line, and sometimes by an arc of a circle; the latter of which is the case when we speak of the distance of two stars from each other.

DOMINICAL

DOMINICAL LETTER, one of the first seven letters of the alphabet, which is usually marked in red, and employed in the Almanack for distinguishing the Sundays throughout the year.

DRACO, or the Dragon, a northern constellation consisting of forty-nine stars.

DRAGON'S HEAD, or the Ascending Node, is the northern intersection of the moon's orbit with the ecliptic, which is marked thus ♈.

DRAGON'S TAIL, or the Descending Node, is the southern intersection of the moon's orbit with the ecliptic, which is marked thus ♏.

E.

EARTH, the globe which we inhabit; one of the seven planets, and the third in order from the sun.

ECCENTRICITY, the distance between the center of an ellipsis and either of its foci.

ECLIPSE of the sun, an obstruction of his light, occasioned by the interposition of the dark body of the moon between him and our sight.

ECLIPSE of the moon, a deprivation of her light, occasioned by the interposition of the earth between the sun and moon.

ECLIPTIC, a great circle of the sphere, in which the sun always appears to move; so called, because eclipses generally happen when the moon is in or near this circle. The obliquity of the ecliptic is the angle it makes with the equator, which is now about 23 degrees 28 minutes.

ELEVATION of the Pole, is an arc of the meridian contained between the pole and the horizon; which is always equal to the latitude of the place, or the distance of the zenith from the equator.

ELONGA-

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ELONGATION, the angular distance of a planet from the sun, as it appears to a spectator upon the earth.

ELEMENTS, in Astronomy, the requisites necessary to determine the theory of a planet, in order to calculate its position, motion, &c.

ELIPSIS, a figure formed by cutting a cone obliquely to its axis: It is in a curve of this kind that the planets move round the sun, and the satellites round their primaries.

EMERSION, the time when any planet that is eclipsed begins to recover its light again.

EPACT, the moon's age at the end of the year, or the difference between the solar year and the lunar one.

EPOCHA, the same as *Æra*, a period from whence Chronologers and Astronomers begin their computations.

EQUATIONS, certain quantities by which we estimate the inequalities in the motion of a planet: The moon, being subject to many irregularities, has a great number of equations.

EQUATION of time, the difference between equal time and apparent, or that shewn by a perfectly true clock and a sun-dial.

EQUATOR, a great circle which separates the northern from the southern hemisphere, and being referred to the heavens is called the **EQUINOCTIAL**.

EQUINOXES, the two points where the ecliptic cuts the equator; so called, because, when the sun is in either of these situations, the days and nights are equal to each other.

EQUULUS, or *Equus Minor*, the Colt, a constellation in the northern hemisphere consisting of twelve stars.

ERIDANUS, the river, a southern constellation containing seventy-two stars.

EVECTION,

EVECTION, an inequality in the motion of the moon, by which, at her quarters, her mean place differs from her true one by about $2\frac{1}{2}$ degrees more than at her conjunction and opposition.

ETHER, a fine subtile fluid, which is supposed to fill the whole celestial space between the heavenly bodies and our atmosphere.

G.

GALAXY, or the Milky-way, a large irregular zone or band of light which encompasses the heavens.

GEMINI, the Twins, a zodiacal constellation consisting of ninety-four stars.

GEOCENTRIC place of a planet, is that position which it has when seen from the earth.

GEORGIUM SIDUS, a new planet, lately discovered by Mr. Herschel, being the seventh in order from the sun, and the most distant of any in the system.

GOLDEN NUMBERS, a series of numbers proceeding from one to nineteen, which are used in the almanack for determining the times of new and full moons.

GREGORIAN YEAR, so called from Pope Gregory XIII. who reformed the calendar in the year 1582; which reformation was not used in England till 1752.

GREYHOUNDS, a northern constellation consisting of twenty-four stars.

GRUS, the Crane, a southern constellation composed of fourteen stars.

H.

HELIACAL rising of a star, is when it emerges from the sun's rays, and appears above the horizon before him in the morning.

E e

HELIACAL

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HELICAL setting of a star, is when it is so hid in the sun's beams, as not to be seen above the horizon after him in the evening.

HELIOCENTRIC place of a planet, is that in which it would appear to a spectator placed in the sun.

HEMISPHERE, the half of a globe or sphere when it is cut through its center in the plane of one of its great circles.

HERCULES, a northern constellation composed of ninety-two stars.

HESPERUS, a name given to the planet Venus when she appears in the evening.

HETEROCII, a name given to the inhabitants of the temperate zones, because their shadows at noon always fall one way.

HIRUNDO, the Swallow, a southern constellation composed of eleven stars.

HORIZON, (Sensible,) a circle which separates the visible hemisphere from the invisible one, or that which is the boundary of our sight.

HORIZON, (Rational,) a great circle which is parallel to the former, and whose two poles are the zenith and nadir.

HOURLY CIRCLES, the same with meridians, or great circles which pass through the poles of the world, and are perpendicular to the equator.

HOUR, the 24th part of a natural day, which Astronomers always begin to reckon from noon.

HYDRA, a southern constellation composed of fifty-three stars.

HYPOTHESIS, a supposition, a system formed upon some principle which has not been proved.

IMMER-

I.

IMMERSION, the moment when an eclipse begins, or when a planet enters into the dark shadow.

INCLINATION, the angle which the orbit of one planet makes with that of another.

INDUS, a southern constellation composed of twelve stars.

INFERIOR PLANETS, are those that move at a less distance from the sun than the earth; which are Mercury and Venus.

INGRESS, is the sun's entrance into any sign or other part of the ecliptic.

INTERCALARY DAY, the odd day, which is made up of the six hours every fourth or leap-year.

JULIAN YEAR, the account of time instituted by Julius Cæsar, which is now called the old stile.

JUPITER, the largest planet in our system, and the fifth in order from the sun.

L.

LATITUDE of a place, is its distance from the equator, reckoned in degrees, minutes, &c. upon the arc of a great circle which is perpendicular to it.

LATITUDE of a star or planet, is its distance from the ecliptic, reckoned in degrees, minutes, &c. upon the arc of a great circle which is perpendicular to it.

LEAP YEAR, the same with Bissextile; so called from there being a day more in that year than in a common one.

LEO, the Lion, a zodiacal constellation consisting of ninety-one stars.

LEO MINOR, the Little Lion, a northern constellation consisting of twenty stars.

LESSER CIRCLES of the sphere, are those whose planes do not pass through its center.

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- LEPUS**, the Hare, a southern constellation composed of twenty-five stars.
- LIBRA**, the Balance, one of the twelve signs of the zodiac, into which the sun comes about the 20th of September, or the beginning of autumn.
- LIBRATION**, a term made use of to express a sort of tremulous motion of the moon, by which some part of her surface, near the borders, becomes visible and invisible alternately.
- LYNX**, a northern constellation, consisting of fifty-five stars.
- LIZARD**, a northern constellation, consisting of twelve stars.
- LONGITUDE** of a place, is its distance east or west from the first meridian, reckoned in degrees, minutes, &c. upon the equator.
- LONGITUDE** of a star or planet, is its distance from the first point of Aries, reckoned in degrees, minutes, &c. upon the ecliptic.
- LUCIDA LYRA**, a fixed star of the first magnitude in the constellation Lyra.
- LUCIFER**, the morning star, Venus, so called when she is in the east, and rises before the sun.
- LUMINARIES**, the sun and moon, so called by way of eminence, on account of their extraordinary lustre, and the great light they afford us.
- LUNAR ASPECTS**, are those which the moon makes with any of the other planets; as when she comes in opposition, trine, quartile, &c.
- LUNATION**, the time between one new moon and another, which is greater than the periodical month by two days and about five hours.
- LUNI-SOLAR YEAR**, a period made by multiplying the cycle of the moon 19 by that of the sun 28.

LUPUS,

LUPUS, the Wolf, a southern constellation consisting of thirty-six stars.

LYRA, a constellation of the northern hemisphere, consisting of twenty-four stars.

M,

MAGNITUDES; the stars are divided into six sizes, or classes; of which the brightest are called stars of the first magnitude; the next in brightness to these stars of the second magnitude; and so on.

MARS, a primary planet belonging to the solar system, which is the fourth in order from the sun, and whose magnitude is about four times less than that of the earth.

MEAN motion of a planet, is that which would take place if it moved in a perfect circle, and equally every day.

MEDIUM COELI, the mid-heaven, that degree of the ecliptic which is upon the meridian at any time of the day or night.

MERCURY, a primary planet, the first in order from the sun, and whose magnitude is about fifteen times less than that of the earth.

MERIDIAN, a great circle of the sphere, which passes by the zenith and poles, and is perpendicular to the horizon; it is so called, because when the sun is upon this circle it is always mid-day or noon.

METONIC YEAR, the same with the cycle of the moon; a period invented by Meton, a Greek philosopher, who lived in the eighty-sixth olympiad, or about 430 years before Christ.

MICROMETER, an instrument by which the apparent magnitudes of objects, viewed through telescopes or microscopes, are measured with great exactness.

MINUTE, the 60th part of an hour in time, or of a degree in motion.

MONOCEROS, a southern constellation, consisting of thirty-two stars.

MONS MÆNALUS, a northern constellation, consisting of eleven stars.

MONTH, (lunar, or periodical,) a period of about twenty-seven days, seven hours, and forty-three minutes, which is the time the moon is in passing from one point of her orbit to the same point again.

MONTH, (synodical,) a period of about twenty-nine days and a half, which is the time between one conjunction of the sun and moon and another.

MONTH, (solar, or calendar,) the time the sun takes to move through one of the signs of the zodiac, which, at a mean, is about thirty days and a half.

MOON, a secondary planet, or satellite, attending the earth, which she regards as the center of her motion.

MUSCA, the Fly, a northern constellation, consisting of six stars.

N.

NADIR, that point in the heavens which is directly under our feet.

NEBULÆ, clusters of small stars which have been discovered by the telescope in different parts of the heavens, and are so called from their cloudy appearance.

NOAH'S DOVE, a southern constellation, composed of ten stars.

NOCTURNAL ARC, is that space of the heavens which the sun apparently describes from the time of his setting to the time of his rising.

NODES, the two points where the orbit of a planet intersects the plane of the ecliptic.

NONA-

NONAGESIMAL DEGREE, the 90th degree, or highest point of the ecliptic, at any given time of the day or night.

NORTHERN SIGNS of the ecliptic, are those six which lie to the north of the equinoctial; as Aries, Taurus, Gemini, Cancer, Leo, and Virgo.

NUCLEUS, a term used by Hevelius for, the head of a comet, and by others for the central parts of the planets.

O.

OBLIQUE ASCENSION, is an arc of the equinoctial contained between the first degree of Aries, and that point of it which rises with the center of the sun or a star.

OBLIQUE SPHERE, is that position of the globe, in which either of the poles are elevated above the horizon any number of degrees less than ninety.

OCCULTATION, is when a star or planet is hid from our sight by the interposition of the moon, or some other planet.

OCTANT, an aspect of the planets when they are forty-five degrees distant from each other.

OPHIUCHUS, or Serpentarius, a northern constellation, consisting of sixty-seven stars.

OPPOSITION, an aspect of the stars or planets when they are a hundred and eighty degrees distant from each other; which in the Ephemeris is marked 8.

ORBIS MAGNUS, the orbit of the earth, which is made by its annual revolution round the sun.

ORBIT, the curve or path which a planet describes in its course round the sun.

ORION, a southern constellation, consisting of ninety-three stars.

P.

PARALLAX, the difference between the places of any celestial object, as seen from the surface of the earth and from its center.

PARALLAX of the earth's annual orbit, is the angle at any planet which is subtended by the distance between the sun and earth; or it is that change of place in the planets, which arises from their being seen from different points of space, as the earth moves round the sun.

PARALLELS of latitude, small circles of the sphere, which are drawn parallel to the equator.

PAVO, the Peacock, a southern constellation, composed of fourteen stars.

PEGASUS, a constellation in the northern hemisphere, consisting of sixty-seven stars.

PENDULUM, a body that swings backwards and forwards about a fixed point; and which, on account of its equal vibrations, is made use of for measuring time.

PENUMBRA, a faint shadow which accompanies an eclipse, and occasions a partial obscurity of the body to that part of the earth on which it falls.

PERIOECI, those inhabitants of the earth who live under the same parallels of latitude, but on opposite sides of the meridian.

PERIGEON, that point of a planet's orbit in which it is at its least distance from the earth.

PERIHELION, that point of a planet's orbit in which it is at its least distance from the sun.

PERIOD, a certain length of time after which eclipses, and other celestial phenomena, return again in the same manner as before.

PERISCHII, the inhabitants of either of the frozen zones; so called, because their shadows go round them for six months,

- months, or fall towards opposite points of the compass.
- PERSEUS**, a constellation in the northern hemisphere, consisting of sixty-seven stars.
- PHASES**, the several appearances of the moon and planets, according as a greater or less part of their illuminated hemispheres are presented to our sight.
- PHOENIX**, a southern constellation, consisting of thirteen stars.
- PHOSPHOR**, a name given to Venus when she is a morning star.
- PROCYON**, a fixed star of the second magnitude, in the constellation Canis Minor.
- PISCES**, the Fishes, a zodiacal constellation, consisting of a hundred and ten stars.
- PISCES VOLANS**, the flying Fish, a southern constellation, consisting of seven stars.
- PLANETS**, (Primary,) those bodies, in our system, that regard the sun as the center of their motions; the number of which is seven, Mercury ☿, Venus ♀, the Earth ☾, Mars ♂, Jupiter ♃, Saturn ♄, and the Georgium Sidus.
- PLANETARIUM**, an instrument made use of for showing the phenomena of the planets; see Plate 20.
- PLEIADES**, seven remarkable stars in the constellation Taurus.
- POLAR CIRCLES**, two small circles of the sphere, twenty-three degrees and a half distant from the poles: that about the north pole is called the arctic circle, and the one about the south pole the antarctic circle.
- POLE STAR**, a star of the second magnitude, in the tail of the Great Bear; so called from its being situated near the north pole of the world.

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POLES of the World, those two points upon the earth's surface which are at the extremities of the earth's axis; or, when referred to the heavens, the two points directly over them.

PRIMUM MOBILE, the first mover, an immense sphere, which, in the Ptolemaic system, was supposed to turn round the earth, as a center, every twenty-four hours, and to carry with it the sun, moon, and planets.

PRECESSION of the equinoxes, a slow motion of the two points where the equator intersects the ecliptic, which are found to go backwards about fifty seconds a year.

Q.

QUADRAGESIMA, the first Sunday in Lent, so called because it is about the 40th day before Easter; and for a like reason, the three preceding Sundays are called Quinquagesima, Sexagesima, and Septuagesima.

QUADRANT, the fourth part of a circle, or an instrument made use of for measuring angles, and taking the altitudes of the celestial bodies.

QUADRATURES, or quarters; those phases of the moon which take place between the conjunction and opposition, and between the opposition and conjunction: one being called the first quarter, and the other the third.

QUARTILE, an aspect of the planets when they are ninety degrees, or a quarter of the zodiac distant from each other; which in an Ephemeris is denoted by $\square$.

R.

REFRACTION, is that variation which the rays of light suffer in passing through mediums of different densities, which occasions the heavenly bodies, when

viewed obliquely through the atmosphere, to appear at a greater height above the horizon than they really are.

REGULUS, a fixed star of the first magnitude in the heart of the constellation Leo.

RIGEL, a fixed star of the first magnitude in the left foot of Orion.

RETROGRADE, an apparent motion of the planets in some parts of their orbits, when they seem to go backwards, or contrary to the order of the signs.

REVOLUTION, is that motion by which the heavenly bodies, in a certain time, return again to the same points of their orbits.

RIGHT ASCENSION, is that degree of the equator which comes to the meridian with the sun, moon, or star, reckoning from the first point of Aries.

ROTATION, the motion of any heavenly body round its axis.

S.

SAGITTARIUS, the Archer, a zodiacal constellation, consisting of forty-eight stars.

SAGITTA, the Arrow, a northern constellation, consisting of thirteen stars.

SATELLITES, secondary planets, or moons which revolve round the primary planets in the same manner as those primaries revolve round the sun.

SATURN, a primary planet, the sixth in order from the sun, and whose magnitude is about a thousand times greater than that of the earth.

SCORPIO, a zodiacal constellation, consisting of forty-four stars.

SECOND,

SECOND, the sixtieth part of a minute, either of time or motion.

SERPENS, the Serpent, a northern constellation, consisting of fifty stars.

SERPENTARIUS, a northern constellation, composed of sixty-seven stars.

SEXTANS URANIE, a southern constellation, consisting of four stars.

SEXTILE, an aspect of the heavenly bodies when they are sixty degrees distant from each other, and is denoted in an Ephemeris by *.

SIDEREAL YEAR, is that space of time which the sun takes in moving through the ecliptic, from any fixed star to the same star again.

SIGNS, the twelve constellations of the zodiac, Aries ♈, Taurus ♉, Gemini ♊, Cancer ♋, Leo ♌, Virgo ♍, Libra ♎, Scorpio ♏, Sagittarius ♐, Capricornus ♑, Aquarius ♒, Pisces ♓.

SOBIESKI'S SHIELD, a northern constellation, consisting of eight stars.

SOLSTITIAL POINTS, are the two signs of the zodiac, Cancer and Capricorn, at which the ecliptic touches the tropics, and into which the sun enters on our longest and shortest days.

SOUTHERN FISH, a constellation in the southern hemisphere, composed of fifteen stars.

SOUTHERN TRIANGLE, a constellation in the southern hemisphere, consisting of five stars.

SOUTHING of the stars, the time when they culminate or come to the meridian.

STARS, (fixed,) those bodies which shine by their own light, and are not subject to motion.

STATIONARY,

STATIONARY, a planet is said to be stationary when it has no apparent motion.

STILE, the manner of reckoning time from some particular period or remarkable event.

SUPERIOR PLANETS, are those which move at a farther distance from the sun than the earth, and are Mars, Jupiter, Saturn, and the Georgium Sidus.

SYNODICAL MONTH, the space of time from any new moon to the following one, which is at a mean twenty-nine days, twelve hours, and forty-five minutes.

SYRIUS, a fixed star of the first magnitude, in the constellation Canis Major, which is the brightest in the heavens.

SYSTEM, a number of bodies revolving round a common center, as the planets and comets move round the sun.

SYZIGIES, those points of the moon's orbit, in which she is at the time of her new and full.

T.

TAURUS, the Bull, a zodiacal constellation, consisting of one hundred and nine stars.

TELESCOPIC STARS, those stars which are only discoverable by means of a telescope.

TEMPERATE ZONES, those parts of the earth contained between the tropics and polar circle.

TORRID ZONE, that part of the earth which is contained between the two tropics.

TRANSIT, is the passing of one celestial body before another, so as to render any part of it invisible.

TRIGONUS MAJOR, the Great Triangle, a northern constellation, consisting of ten stars.

TRIGONUS MINOR, the Little Triangle, a northern constellation, consisting of five stars.

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TRINE, an aspect of the planets, when they are a hundred and twenty degrees distant from each other; and in an Ephemeris is denoted by Δ .

TROPICS, two small circles of the sphere which are parallel to the equator, and twenty-three degrees twenty-eight minutes distant from it.

TWILIGHT, is that faint light which we perceive before the rising of the sun, and after his setting, and is occasioned by the refraction of the earth's atmosphere.

V.

VECTOR RADIUS, a line supposed to be drawn from any planet to the sun, which moving with the planet, describes equal areas in equal times.

VENUS, a primary planet, the second in order from the sun, and whose magnitude is about one-ninth less than that of the earth.

VIRGINIS SPICA, a fixed star of the first magnitude in the constellation Virgo.

VIRGO, the Virgin, a zodiacal constellation, consisting of ninety-three stars.

URSA MAJOR, the Great Bear, a northern constellation, consisting of one hundred and five stars; sometimes also called Charles's Wain.

URSA MINOR, the Little Bear, a northern constellation near the pole, consisting of twelve stars.

VULPES, the Fox, a northern constellation, consisting of twenty-nine stars.

X.

XIPHIAS, the Sword-fish, a southern constellation, consisting of seven stars.

YEAR,

Y.

YEAR, the space of time taken up by the sun in going through the twelve signs of the zodiac.—See **SIDE-REAL YEAR**, &c.

Z.

ZENITH, that point of the heavens which is perpendicularly over our heads.

ZODIAC, a zone or girdle, surrounding the heavens, of about eighteen degrees broad, in the middle of which is the ecliptic, and in which the orbits of all the planets are included.

ZONE, a division of the sphere, contained between any two parallels of latitude.

F I N I S.

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